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Waste and Water International, Emeryville, CA

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Municipal Environmental Research Lab.
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TECHNOLOGY ASSESSMENT
OF
WETLANDS FOR MUNICIPAL WASTEWATER TREATMENT

by

Henry C. Hyde, P.E.
Roanne S. Ross, P.E.
WWI Consulting Engineers
Emeryville, California 94608

Francesca Demgen
Demgen Aquatic Biology
Vallejo, California 94590

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Project Officer

Jon H. Bender
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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16. ABSTRACT

The innovative and alternative technology provisions of the Clean Water Act of 1977 (PL 95-217) provide financial incentives to communities that use wastewater treatment alternatives to reduce costs or energy consumption over conventional systems. Some of these technologies have been only recently developed and are not in widespread use in the United States. In an effort to increase awareness of the potential benefits of such alternatives and to encourage their implementaion where applicable, the Municipal Environmental Research Laboratory has initiated this series of Emerging Technology Assessment reports. This document discusses the applicability and technical and economic feasibilty of using natural and artificial wetland systems for municipal wastewater treatment facilities.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natual environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development are the necessary first steps in problem solution, and involve defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communication link between the researcher and the user community.

The innovative and alternative technology provisions of the Clean Water Act of 1977 (PL 95-217) provide financial incentives to communities that use wastewater treatment alternatives to reduce costs or energy consumption over conventional systems. Some of these technologies have been only recently developed and are not in widespread use in the United States. In an effort to increase awareness of the potential benefits of such alternatives and to encourage their implementation where applicable, the Municipal Environmental Research Laboratory has initiated this series of Emerging Technology Assessment reports. This document discusses the applicability and technical and economic feasibilty of using natural and artificial wetland systems for municipal wastewater treatment facilities.

Francis T. Mayo
Director
Municipal Environmental Research
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ABSTRACT

Wetland is a general term which applies to different aquatic habitat types. Wetlands may be defined as an area covered periodically or permanently with water of varying depths and which supports hydrophilic vegetation. Wetlands may be fresh or saline, and some are associated with larger bodies of water.

There are various types of natural and artificial wetlands being used for wastewater treatment: marshes, shallow ponds, bogs, cypress domes, cypress stands, and swamps. All of the wetland systems reviewed for this assessment were either fresh or brackish, and treated domestic wastewater to various degrees. A wastewater wetland may also provide the secondary benefits of wildlife habitat, and recreational and educational opportunities.

The research completed on wastewater wetland systems is extensive. Results of bench and pilot scale projects have produced a number of full-scale systems. These full-scale systems include artificial and natural marshes, peatlands, swamps, marsh/pond/meadows and bogs.

Wastewater treatment in a wetland system is accomplished through biological, physical and chemical reactions. Although the processes involved are fairly well understood, there are still questions as to the roles that individual reactions play in the treatment process. To further complicate any attempt at modeling the treatment process, it is probable that the proportion of significance assigned to each treatment reaction varies with specific project conditions. The major components of the wetland system which perform the wastewater treatment are: algae, macrophytes (larger, rooted plants), bacteria, zooplankton, and the substrate (bottom soils).

A wastewater wetland system can provide primary, secondary, or advanced treatment. The need for open land or existing wetland areas makes this technology compatible with areas outside of urban centers. Capital costs, operational costs, and energy requirements are significantly less than conventional treatment alternatives. Land acquisition and proximity to the wastewater source are the major variables affecting cost.

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WWI Consulting Engineers

Mr. Henry C. Hyde, P.E.*	: Project Manager
Ms. Roanne Ross, P.E.	: Project Engineer

Demgen Aquatic Biology

Ms. Francesca Demgen	: Aquatic Biologist

US Environmental Protection Agency

Mr. John M. Smith, P.E.*	: Chief: Urban Systems Management Section, Wastewater Research Division
Mr. Robert P.G. Bowker, P.E.*	: Project Officer, Wastewater Research Division

* Current Affiliation:

Henry C. Hyde

Henry Hyde & Associates
Star Box 605
Sausalito, CA 94965

John M. Smith
Robert P.G. Bowker

J.M. Smith & Associates
7373 Beechmont Avenue
Cincinnati, OH 45230

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SECTION 1

TECHNOLOGY DESCRIPTION

INTRODUCTION

The utilization of wetland for wastewater treatment has as its base its historical/ecological function. Riverine wetlands often occur where a stream enters a river, lake or bay. Here the velocity of the tributary's water drops and the silt carried by the stream is deposited in the marsh, swamp or peatland. Vegetation develops in this fertile, shallow area and acts as a filter for water entering the marsh and larger bodies of water. The wetland is a sink for nutrients and organic debris during most of the year. The streams continually supply the wetland with nutrients, creating a highly productive system. The system then can support a wide variety of wildlife. Wetlands serve as important rearing grounds for animals and fishes which live above the marshes in the streams and below the marsh in the rivers, lakes and bays. The marshes of this country's great rivers have been employing this living filter mechanism to treat domestic wastes for many years with little recognition of their contribution towards meeting the goals of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and the Clean Water Act of 1977 (PL 95-217). The recent interest in the ability of wetlands to treat wastewater is fostered by economic concerns and the acknowledgement that wastewater may be viewed as a resource.

Wetland is a general term which applies to a number of different aquatic habitat types. A wetland may be defined as an area covered periodically or permanently with water of varying depths and which supports hydrophilic vegetation. Wetlands may be fresh or saline, and some are associated with larger bodies of water. Table 1 describes various types of natural and artificial wetlands. Wetlands are similar to aquaculture systems; however, a distinction can be made.

Aquaculture is the production of aquatic organisms, both flora and fauna, under controlled conditions, primarily for the generation of food, fiber, and fertilizer. There is a separate technology assessment as a part of this series which covers the subject of aquaculture systems used for wastewater treatment.

There are a number of types of natural and artificial wetlands being used for wastewater treatment: marshes, shallow ponds, bogs, cypress domes, cypress stands, and swamps. All of the wetland systems reviewed for this assessment were either fresh or brackish, and treated domestic wastewater to various degrees. A wastewater wetland may also provide the secondary benefits of wildlife habitat, recreational and educational opportunities, stream flow augmentation, and harvestable plant byproducts.

Table 1. **WETLAND TYPES** (Reference 31)

Classification	Type	Description
Natural	Riverine	Wetland located adjacent to rivers or streams; for example, marshes, shallow ponds, or wet meadows.
	Laucustrine	Wetland adjacent to or near lakes; for example, marshes, shallow ponds, or wet meadows.
	Palustrine	Wetland isolated from open bodies of water; for example, bogs and cypress domes.
	Tidal	Wetland areas subject to tidal action with various flooding regimes.
Artificial	Marshes	Shallow depths with emergent plants such as cattails and bulrushes covering nearly the entire surface. Basin may be sealed or unsealed.
	Ponds	Somewhat deeper than marshes with an open water surface. May contain submerged plants and plants on the banks.
	Marsh/Pond	A combination of the two components above.
	Trench	Narrow ditches, lined or unlined, planted with vegetation, usually bulrushes.

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The primary components of a wetland treatment system are influent wastewater and a shallow, mostly vegetated basin with or without a point source discharge. The submerged and emergent plants, their associated microorganisms, and the wetland soils are responsible for the majority of the treatment effected by the wetland. Wastewater wetland systems can provide primary, secondary, or advanced treatment. The need for open land or existing wetland areas makes this technology compatible with areas outside urban centers. Capital costs, operation costs, and energy requirements are low compared with conventional treatment alternatives. Land acquisition and proximity to the wastewater source are the major variables affecting cost.

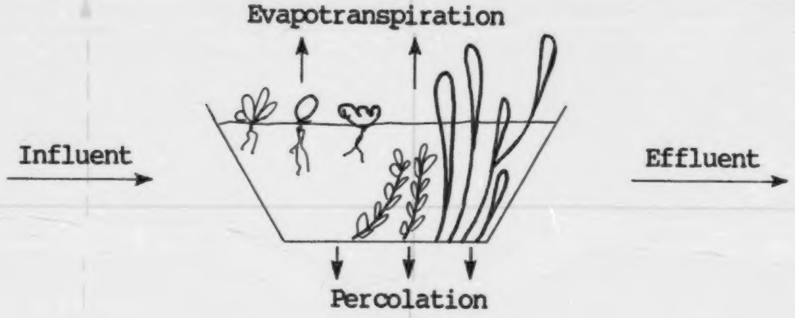
PROCESS FLOW PATHS IN NATURAL AND ARTIFICIAL WETLANDS

A wetland environment can be used to accomplish a variety of levels of treatment and the desired level of treatment of the influent will affect the flow path. Comminuted, aerated, raw sewage can be treated through a multi-cellular artificial system. The water progresses through a series of plots until the desired quality is reached. Primary or secondary effluent could also serve as wetland influent. Process flow diagrams for natural and artificial wetlands are shown in Figure 1.

Natural Wetlands

Natural marshes, bogs, cypress domes, and strands are all in use as wastewater treatment systems. Table 2 describes distinguishing characteristics of each wetland type. Very few physical modifications are necessary to adapt a natural wetlands for treatment. Inlet structures are required except when the wastewater has been discharged to a tributary upstream of the wetland. Stand pipes, overflow weirs and discharge pipes have been used to introduce the wastewater to the wetlands in a single location. It may be necessary to have smaller multiple inlets to avoid erosion and provide even distribution of the water over the entire surface of the wetland. In such cases, multiple-gated, aluminum irrigation pipe has been successfully used. Depending on the configuration of the wetland's perimeter, a barrier levee may be necessary to contain the wastewater. Any levees which become part of the system should be constructed so that they can support a maintenance vehicle. This allows access for maintenance of the wetland and the levee itself. If the wetland lies in a deep natural depression such as a bog, or it is contiguous with a larger body of water, a barrier levee may not be required.

A natural wetland is normally an expansive area. Although there are no physical barriers subdividing the wetland, often


Evapotranspiration
Influent
Effluent
Percolation

Possible Influents

1. Aerated Raw sewage
2 Primary Effluent
3. Secondary Effluent

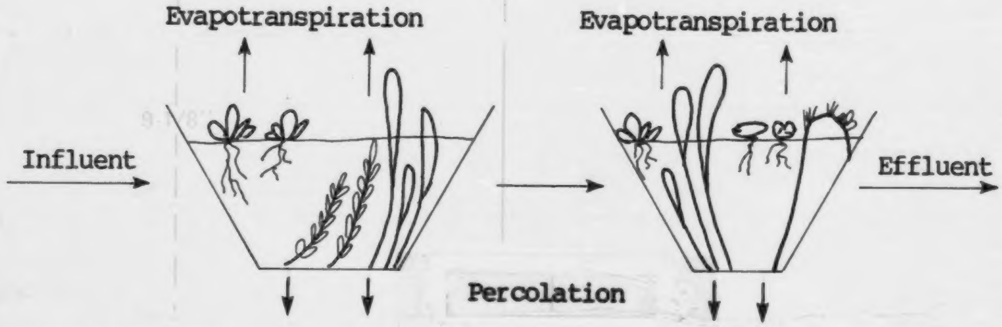
Wetland Vegetation Types

1. Submergents
2. Emergents
3. Floating
4. Phreatophytes

Effluent Disposal

1. Non-point discharge
2. Percolation
3. Point discharge

A. Natural Wetland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Possible influents

1. Aerated raw sewage
2. Primary Effluent
3. Secondary Effluent

Wetland Vegetaton Types

1. Submergents
2. Emergents
3. Floating
4. Phreatophytes

Effluent Variations

1. Point discharge
2. Non-point discharge
3. Percolation

Flow Pattern Variations

1. Smaller multiple cells.
2. Cells subdivided by internal levees.
3. Islands to direct flow

B. Artificial Wetland

Figure 1. **Process flow diagrams - natural and artificial wetlands.**

Table 2. DISTINGUISHING CHARACTERISTICS OF VARIOUS NATURAL WETLAND TYPES

Type	Vegetation	Physical Characteristics
Marshes	Cattails, bulrushes, duckweed. Submergents and bank plants vary with the locality.	To 1.5 m. deep. Vegetation often interspersed with small areas of open water.
Bog/ Peatland	Sphagnum moss, leather-leaf, sedges, willows. Dense, thick, low vegetation.	Very few open water areas. Often located in a deep depression. May be isolated from other bodies of water.
Cypress Dome	Cypress trees, duckweed.	Usually 0.4 - 10 ha. in size. Shape -- irregular circles. No regular discharge - occasional overflow.
Cypress strand/swamp	Trees: Cypress, willow, ash, others. Also marshy areas, wet meadows, shallow channels.	Strand: Linear, flow-through system. Swamp: Dense vegetation, variable shapes, depth less than 1.5 m.

it is composed of various habitat types. For example, a marsh might have areas of open water among the emergents, or a peatland may have areas of water tolerant trees and shrubs in addition to the sphagnum, leather leaf, sedges, etc. The wetland may have established channels or the water may sheet flow over the entire surface. The wetland often merges with a broad open body of water, such as a river or lake. Peatlands, isolated bogs, and cypress domes are an exception to this process. They frequently have no surface discharge; instead, all water loss is by percolation, evaporation, and/or transpiration.

A natural wetland usually has a diversity of plant species indigenous to its location; Table 2 lists some common vegetation types. The plants are a component of the physical process involved in wastewater treatment due to their directional effect on the flow of wastewater through the wetlands. They also serve as a surface for colonization by bacteria, algae and microorganisms which act upon the wastewater and react with the vegetation. The four categories of plants which will influence the flow path of water are floating plants, submergents, emergents, and phraetophytes (plants rooted on the banks but growing out over the water). Table 3 gives examples of each of these types of wetland plants. The type and density of plants also influences the rate of evapotranspiration, hence the total water volume.

Table 3. **EXAMPLES OF WETLAND VEGETATION**

Vegetation Type	Common Name	Latin Name
Floating	Duckweed Waterlily	*Lemna* spp. *Nymphaea* spp.
Submergents	Pond Weed Water Weed	*Potamogeton* spp. *Elodea* spp
Emergents	Cattail Bulrushes	*Typha* spp. *Scirpus* spp.
Phreatophytes	Smartweed Fat Hen	*Polygonum* spp. *Atriplex* spp.

The soils are an important process component. The biological and chemical composition of the soil matrix determines the reactions possible for removal of pollutants. The particle size and soil type also determine the percolation capacity of the wetland.

Artificial Wetland

The physical processes of an artificial wetland are more easily managed than in a natural wetlands. This ability to manipulate the flow path allows more efficient use of space. Often natural wetlands used for wastewater treatment are very large. The ability to control the flow and vegetation in an artificial wetland allows treatment to occur in a smaller area.

An artificial wetland is usually composed of multiple plots. Each unit normally has one inlet and discharge structure. Additional structures are helpful to allow flow path modifications for maintenance, drying cycles, or treatment variations. The flow within each plot can be directed by islands, vegetation, internal baffles or levees, and occasionally by mechanical devices. The number of wetland units comprising the treatment system depends on the topography

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of the site, influent water quality, and desired effluent quality.

There are two types of artificial wetlands in use: discharge and seepage. The former has one or more defined discharge points. Seepage wetlands have no final discharge point; instead the water percolates into the soils, evaporates or transpires into the atmosphere.

The previous discussion on Natural Wetlands concerning vegetation and soils also applies to artificial wetlands. When an artificial wetland is created, some vegetation will need to be planted. Cattails and various species of bulrushes and reeds grow nationwide; root stock for some species may be transplanted to the new area. Seeds and root stock are also available commercially. Levees and banks may be seeded with a grass mixture. Native plants will then colonize the wetland area and establish good cover and erosion protection. Harvesting has generally been found not to be necessary. The potential of harvesting wetland biomass for use in energy production is being investigated. A high density of plants is usually considered desirable. Dredging the substrate may become necessary in the long term, perhaps every 15 to 20 years. Routine harvesting, however, has not been necessary.

COMMON SYSTEM COMPONENTS AND MODIFICATIONS

Inlet structures of the following types can be found in use: stand pipes, weirs, gate valves, and long aluminum irrigation pipes with multiple flap gates. The first three types have been used in artificial wetlands and cypress domes while the last type has been used in natural wetlands including cypress strands, bogs, and peatlands. Effluent discharge structures can be weirs, gate valves, or flap gates.

The substrate (the wetland soils) is an important process component. In some cases, the substrate may be porous and therefore, reduce or eliminate point discharge from the system. In other cases the substrate may be sealed and may consist of native or imported clays, or an artificial sealer such as a plastic liner. Plastic liners are sometimes used in artificial trench systems.

Artificial substrates can be used to enhance or replace vegetation in artificial wetlands. They are colonized by aquatic invertebrates, bacteria, and periphytic algae, thereby enhancing the food chain. These organisms are the same as those found on the submerged portions of plant stems. Therefore, when artificial substrates are used in open water areas, they provide some of the functions of emergent vegetation.

Wind driven circulators or electric aeration devices can be used to influence the flow path and enhance circulation or aeration.

SECTION 2

RECOMMENDATIONS

The use and reliability of wetland as wastewater treatment systems should increase as additional successful experience is gained in the future. Based on this assessment, the following recommendations are made regarding the implementation of wetland wastewater treatment technology:

- Construction and Design of Artificial Wetland Basins. Various methods of basin construction should be studied to determine the most cost-effective method. The design of the basin should be optimized to minimize energy requirements and to facilitate minimum operation and maintenance of the basins.

- Engineering Design Criteria. Research projects should be developed to test design criteria (i.e., surface and organic loadings) for both artificial and natural wetlands. This information is necessary for design of the different wetland types in various geographical locations (warm and cold climates).

- Impacts on Natural Wetlands. There is much controversy regarding the impact of introducing wastewater to a natural wetland. Research should be directed at determining what and how significant the impacts are.

- Labor Requirements. Available information regarding O&M labor requirements is limited. Operating facilities should document actual labor requirements to enable other agencies to accurately estimate labor demands and operational procedures.

- Removal Efficiencies. As shown in Table 26, there is limited data on the removal efficiencies for artificial wetlands. Presently there is very limited published data on the removal efficiency of the following parameters for artifical wetlands: total solids, dissolved solids, suspended solids, TOC, COD, nitrogen, heavy metals, coliforms, and pathogens. For natural wetlands, there is also very limited published data on the removal efficiency of the

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following parameters: refractory organics, pathogens and coliforms.

- o *Costs*. Accurate documentation of the construction and O&M costs should be maintained by operating facilities. This information would be helpful for future cost estimates. Existing documentation of cost is poor.

- o *Information Transfer*. Publication of successful project information in widely read professional publications is needed to inform wastewater agencies of wetland wastewater treatment opportunities. Guidance documents published by EPA for distribution by state and regional regulatory and funding agencies to wastewater management agencies would be useful in promoting the use of wetland treatment technology. Currently, many state and regional agencies are not well informed regarding the benefits of wetland treatment technology.

SECTION 3

DEVELOPMENTAL STATUS OF WETLAND SYSTEMS

INTRODUCTION

The purpose of this section is to give a broad overview of the wetlands treatment research data currently available. Data from one bench scale project, seven pilot/demonstration scale projects and fifteen full-scale projects were utilized in this effort. Many volumes of available data have been condensed into this summary to provide an accurate picture of wetland system performance.

The pilot scale projects described are artificial wetlands. A brief description of each project and a summary of removal efficiencies for key water quality parameters are given. More emphasis is placed on full-scale projects due to their size and operational status. Design criteria and performance data are included for the full scale facilities.

SUMMARY OF RESEARCH FINDINGS

Lab/Bench Scale Research Projects

Lakshman (Reference 21) created an artificial, bench-scale marsh using plants containing bulrush and cattail to treat raw municipal sewage. Initial concentrations of total phosphorus (TP) and total Kjeldahl nitrogen (TKN) were 3.9 - 29 mg/l and 10.3 - 44.0 mg/l respectively. Up to 90 percent removal was achieved in less than 20 days. Lakshman reports that vegetated tanks had continuous removal ability whereas gravel filled tanks reached a saturation level for nutrient removal.

Pilot/Demonstration Scale Research Projects

Small (References 25 and 26) and Woodwell (Reference 38) et. al. tested the ability of two artificial systems: marsh/pond and meadow/marsh/pond over a five-year period. The application rates varied from 420 - 855 cu m/ha-day of comminuted, aerated raw sewage. *Typha* and *Lemna* (cattail and duckweed) were the major vegetation types. Total suspended solids, total coliform and turbidity were high in the effluent. These are, however, normal by-products of a wetland ecosystem. The high iron and manganese levels reflected elevated levels in the

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drinking water supply. The remaining parameters were equivalent to the quality achieved by conventional secondary systems. Table 4 contains a summary of removal rates from the pilot scale wetlands projects.

Cederquist and Roche (Reference 4) conducted a three-year study of treatment and reuse in a pilot project adjacent to the Suisun Marsh in Cordelia, California. An approximately 5 ha site was divided into four shallow ponds and two marshes which received secondary effluent at an average flow rate of 950 cu m/day. Application rates to the ponds were 1.38 cu m/ha/mo (two ponds) and 2.76 cu m/ha/mo (two ponds). Table 4 contains a summary of removal efficiencies.

Nute (Reference 23) describes a pilot study of a 74 sq m surface area pond with artificial substrates in place of vegetation in Martinez, California. The pond discharges to a subsurface irrigation system for the growth of redwood trees. The pond receives 13.6 cu m/day of secondary effluent; one-third is utilized by the irrigation system and two-thirds is discharged. Creation of wildlife habitat, and improvement of water quality are the goal of the system. Table 4 contains a summary of removal rates.

Spangler, Sloey and Fetter (Reference 27) in Wisconsin studied water quality improvements by plants in four settings: greenhouse, experimental basins, pilot plant and natural marsh. The natural marsh will be discussed in the review of full-scale facilities section. In the greenhouse study, three species of bulrush and iris received 21 liters of primary effluent on a five-day batch basis. Removal rates are given in Table 4. Softstem bulrush (Scirpus validus) was chosen for test purposes in the experimental basin because of the good removal rates in the greenhouse studies. These basins were lined with PVC plastic and the vegetation was planted in gravel. Experiments with both primary and secondary effluent were performed using an application rate of 1.9 liters/minute to give a retention time of five hours for the secondary effluent and ten days for the primary effluent. Table 4 lists removal rates achieved. A study was also conducted using softstem bulrush in a "pilot plant" trench, with approximately 112 sq m of surface area. A ten-day retention time was used. The results for tests on both primary and secondary effluent are listed in Table 4.

De Jong (Reference 9) studied artificial marshes for the treatment of sewage from campgrounds in the Netherlands. These studies are prerequisite to larger municipal wetlands treatment systems. Table 4 shows the reduction in BOD, COD, total phosphorus and total Kjeldahl nitrogen achieved by the bulrush and reed marshes.

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TABLE 4. SUMMARY OF REMOVAL EFFICIENCIES FROM PILOT SCALE WETLAND PROJECTS, IN PERCENT

Authors	Influent Type	Wetland Type	Wetland Area	BOD_5	COD	Total P	SS[a]	Nitrate & Nitrite	Ammonia
Small & Woodwell	Aerated Raw Sewage	Meadow/marsh/pond Marsh/pond	2475 m^2 4700 m^2	92 89	90 88	78 71	89 88	73 53	86 58
Cederquist & Roche	Secondary Effluent	Marsh	5 ha	--	--	75	--	80-S[b] Incr-W[c]	Incr.-S 20-W
Nute	Secondary Effluent	Pond with artificial substrates	75 m^2	60	--	25	79	46	22
DeJong	Raw sewage	Marsh	1 ha	96	93	80	--	--	85[d]
Spangler Sloey Fetter	Primary Effluent	Greenhouse Trenches	7200 cm^2	98	86	82	--	--	--
	Primary Effluent	Experimental basins, trenches lined & vegetated	9 m^2	87	75	25	82	--	--
	Secondary Effluent			87	24	17	69	--	--
	Primary Effluent	Pilot Plant Trenches, lined and vegetated	57 m^2	77	71	37	24	--	--
	Secondary Effluent			38	44	64	77	--	--

a) Suspended Solids
b) Summer
c) Winter
d) Kjeldahl Nitrogen

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Two additional pilot/demonstration projects will be mentioned; both are currently in operation and data are being collected. Both projects will supply needed information in defining the treatment capabilities and design criteria for artificial wetlands.

Wile (Reference 36) describes research being conducted in two towns in Ontario, Canada. At Listowel there are two artificial marshes receiving raw aerated sewage and an additional two are planned which will receive lagoon effluent. The flow rates to these four artificial marshes will vary between 10-43 cu m/ day. There is also a marsh/pond/marsh system operating in series which will receive lagoon effluent, loaded at rates between 50 - 200 cu m/day. The town of Bradford's sewage treatment plant is located adjacent to a natural cattail marsh, approximately 1400 sq m in area. The background levels of nutrients will be documented for two years prior to the addition of partially treated wastewater.

The City of Arcata, California is conducting a pilot project to: 1) evaluate the feasibility of using secondary wastewater to enhance the productivity of a freshwater marsh; and 2) test the effectiveness of marshes to reliably treat stabilization pond effluent to tertiary standards (Reference 19 and personal communication with Gearheart). Twelve 0.004 ha experimental marshes are being operated with variable flow rates, detention times and vegetation. Figure 2 shows the design scheme of the twelve plots and Table 5 the design parameters. Current studies are scheduled to be completed in July 1982. Data gathered for the first six-month period are tabulated in Table 6 and 7 (Reference 13).

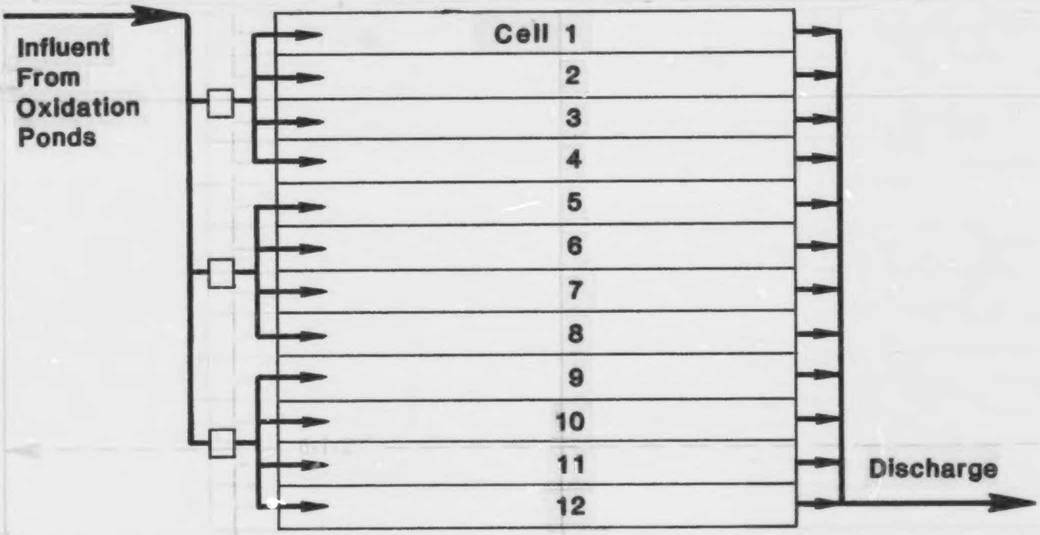

FIGURE 2. Arcata experimental marsh cells – flow diagram (Reference 13).

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Table 5. DESIGN PARAMETERS FOR ARCATA EXPERIMENTAL MARSH CELLS (Reference 19)

Cell Number	Detention Time (Hours)	Influent flow rate (liters/min)	Vegetation Percent coverage Emergents	Vegetation Percent coverage Floating	Vegetation Percent coverage Submergents
1	56	61	70	15	25
2	28	61	65	15	15
3	56	61	50	80	--
4	28	61	55	100	10
5	112	30	85	20	5
6	56	30	90	15	5
7	112	30	65	100	20
8	56	30	30	100	5
9	224	15	75	55	20
10	112	15	70	40	25
11	224	15	65	100	15
12	112	15	65	100	10

Table 6. UNWEIGHTED RANK ORDER OF FIVE EFFLUENT PERFORMANCE PARAMETERS - LOWEST RANKING REPRESENTED HIGHEST PERFORMANCE, ARCATA (Reference 13)

	Marsh Cell Number											
Parameter	1	2	3	4	5	6	7	8	9	10	11	12
BOD	8	3	10	11	7	2	9	12	4	1	6	5
NFR	8	6	11	12	7	5	10	9	4	1	2	3
NH3	10	11	8	9	12	6	5	7	3	4	2	1
Total Coliform	8	9	12	10	5	3	7	11	4	2	6	1
Fecal Coliform	9	5	12	10	11	4	8	7	2	3	6	1
TOTAL	43	34	53	51	42	20	39	46	19	11	26	11

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TABLE 7. Water Quality Data, Weekly Mean Values for the Experimental Marshes, City of Arcata, California (Reference 13)

Marsh Cell No.	BOD mg/l	BOD % removal	COD mg/l	COD % removal	Non-Filterable Residues mg/l	Non-Filterable Residues % removal	Ammonia mg/l	Ammonia % removal	Nitrate mg/l	Nitrate % removal	Turbidity NTU
July 29, 1980 through October 16, 1981											
INFLUENT	27.0		82.5		26.0						21.0
1	6.9	75	59.5	28	6.5	75					11.5
2	9.2	65	59.7	28	6.9	73					8.9
3	11.6	57	63.2	23	10.2	60					13.5
4	14.7	45	70.4	14	12.6	51					13.8
5	6.7	75	54.6	34	3.7	85					7.0
6	6.1	77	54.6	34	4.1	84					5.9
7	10.4	61	65.9	20	12.4	52					12.7
8	12.0	55	65.2	21	10.9	58					12.3
9	5.5	79	59.9	27	3.2	87					8.2
10	3.6	86	53.1	36	4.0	84					4.2
11	4.9	81	60.7	26	6.7	74					6.8
12	6.9	74	56.2	32	4.8	81					4.6
October 1980 through January 1981											
INFLUENT	23.9				31.7		26.6		1.02		22.2
1	13.0	46			9.5	70	22.7	14.6	0.71	30	13.3
2	8.2	66			6.5	79	23.1	13.0	0.99	3	11.0
3	14.0	41			8.5	73	22.0	15.0	0.73	28	15.3
4	14.7	38			10.9	66	22.4	15.7	0.68	33	15.6
5	12.2	49			5.3	83	23.3	13.5	0.71	30	13.0
6	7.9	57			5.0	84	20.6	22.5	0.74	27	10.8
7	13.3	44			10.9	65	20.4	23.3	0.79	23	15.2
8	15.4	36			10.5	66	20.8	21.8	0.77	25	13.7
9	8.5	69			5.5	83	18.4	30.8	1.21	-19	9.0
10	7.8	67			5.4	83	18.5	30.4	1.34	-31	7.6
11	12.0	50			8.2	74	17.4	34.5	0.80	22	7.9
12	10.1	58			7.9	75	16.5	37.9	1.25	-23	8.5

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Predominant emergents are cattail and bulrush; predominant floating vegetation are water starwort (Callitriche palustris) and duckweed, and the predominant submerged vegetation is pondweed (Potamogeton foliasus).

Two general trends on the effects of vegetation for improving water quality have been identified: 1) emergents and submergents have a greater positive effect than floating vegetation; 2) a band of vegetation covering the complete width of the cell has a greater positive effect than sporadic patches covering the same amount of area. The data generated from this project will provide information to help in sizing wetlands for specific levels of treatment and to define the role vegetation plays in the treatment process.

Full Scale Natural Wetland Treatment Projects

Spangler (Reference 27) et. al. studied Brillion Marsh which receives approximately 757 cu m/day (0.2 mgd) from the City of Brillion, Wisconsin sewage treatment plant, as well as natural tributaries. All parameters studied, except total solids and dissolved solids, were reduced by the marsh. Of all the parameters, BOD and coliform levels achieved the greatest reductions. Table 8 contains results from a one-year study. Station I is in a creek, tributary to the marsh, above the sewage effluent discharge. Station II is below the discharge and prior to the marsh. Station III is within Brillion Marsh. Other studies were also done on vegetation nutrient levels and harvesting effects.

Kadlec (Reference 16) describes his studies of the Houghton Lake Peatland Marsh (Michigan) which has received 3790 to 7570 cu m/day (1-2 mgd) of secondary effluent for five consecutive summers. Data concerning standard water quality parameters, nutrients, heavy metals, biomass, pathogens, soils, vegetation nutrient levels, algae, vertebrate and invertebrate fauna have been collected and analyzed in volumes of reports. All nitrogen and phosphorous were removed within a two-hectare area. Total alkalinity, pH, and hardness decreased rapidly from the influent point. Chlorides pass through the wetland with little change, while the chemical oxygen demand increased. Lead, copper, nickel and boron levels were below the limits of detection. No soil erosion or plant mortality occurrred. Suspended solids deposited close to the discharge.

Boyt (Reference 2) et. al. studied a mixed hardwood swamp and cattail/duckweed marsh in Wildwood, Florida, which has received 946 cu m/day (0.25 mgd) of poor quality, secondary effluent for twenty years. Analyses have been done for water quality, sediment nutrient levels, biomass, tree growth and bacteria. Nitrogen, phosphorous and dissolved oxygen levels

Table 8. MEAN VALUES[a] FROM LONG-TERM STUDIES AT BRILLION MARSH
(Reference 27)

Parameter	Tributary Creek Station 1 above wastewater discharge	Tributary Creek Station II below wastewater discharge	Effluent from Marsh	% Reduction
BOD_5	6	27	5	81.5
COD	31	106	60	43.4
Orthophospate	1.3	3.1	2.9	6.4
Total Phosphorous	1.3	3.4	3.0	13.4
Conductivity (umho)	1540	1065	983	7.7
Turbidity (JTU)	26	20	11.3	43.5
Nitrate	1.8	1.2	0.6	51.3
Coliform (log col 100 ml^{-1})	4.76	5.54	4.68	86.2
pH	7.9	7.8	7.4	—
Total Solids	955	707	767	-8.5
Suspended Solids	154	127	90	29.1
Dissolved Solids	801	580	677	-16.7

[a] All values are mg/l unless otherwise indicated in parentheses.

can be seen in Table 9. Fecal coliform and streptococci levels declined rapidly within the swamp. The sediments did not show a build-up of nutrients. Tree growth was more rapid in the experimental swamp with wastewater nutrients present than in the swamp area without wastewater.

Kappel (Reference 17), reports on the discharge of 379 cu m/day 0.1 mgd) of secondary effluent to a 10 ha (25 acre) bog in Drummond, Wisconsin, which began in May 1979. Research encompasses four major areas: water quality, vegetation, small animals, water and nutrient budgets.

Table 9. WATER QUALITY DATA FROM CYPRESS STRAND IN WILDWOOD, FLORIDA
(Reference 2)

Nutrient	Strand Influent	3.7 km down from Inlet	Levels of Dissolved Oxygen	
Total Phosphorus	6.4 mg/l	0.12 mg/l	Control	2.4 mg/l
Total Nitrogen	15.3 mg/l	1.61 mg/l	Test	2.8 mg/l

Data from standard chemical and nutrient analyses summarized through August 1979 show no changes in water quality in the bog's discharge. Nutrient levels in the vegetation thus far are within normal levels for non-wastewater bog plants. The animals to date have not been affected.

The Delaware River estuary system receives large loads of industrial and domestic wastewater. Whigham and Simpson (Reference 35) studied a portion of this vast system. The 500 ha (1240 acre) Hamilton freshwater tidal marsh receives 26,495 cu m/day (7 mgd) of secondary effluent from the Hamiltion Township, New Jersey wastewater treatment facility. Vegetation, soil, algae, and water quality have been studied. Vascular plant productivity is high, ranging from 150-2000 g/sq m/year. Peak algal biomass is less than that for vascular plants and tidal mudflats. Water quality varies with the tide and the season. The authors conclude that the vegetated high marsh acts as a nutrient sink during summer months, and the pond-like area performs a similar function in the winter.

Yonika (Reference 39) describes the effects of a 2,390 cu m/day (0.61 mgd) discharge of secondary effluent by the Town of Concord, Massachusetts to the 19 ha (48 acre) Great Meadows National Wildlife Refuge. The wetland is composed of various vegetation types and water depths. Removal efficiencies have been calculated during various seasons and vegetation types. Average values are listed in Table 10.

The Village of Bellaire, Michigan, discharges approximately 1.1×10^5 cu m (30 mg) of secondary effluent to a 15 ha (36 acre) wetland from approximately May to November each year. Kadlec and Tilton (Reference 15) have published three data reports containing water chemistry and water budget data. Nutrients are of prime concern because the marsh discharges to a recreational lake. Table 11 contains a three-year summary of total dissolved phosphorus and dissolved nitrogen data.

Table 10. AVERAGE ANNUAL REMOVAL EFFICIENCIES FOR GREAT MEADOWS WETLAND, MASSACHUSETTS (Reference 39)

Criteria	Percent Reduction
Ammonia Nitrogen	58%
Nitrate Nitrogen	20%
Nitrite Nitrogen	No reduction
Total Kjeldahl Nitrogen	35%
Total Phosphorus	47%
Ortho Phosphorus	49%
Biochemical Oxygen Demand	67%

Table 11. THREE YEAR SUMMARY OF NUTRIENT REMOVAL FROM BELLAIRE WETLANDS, MICHIGAN (Reference 15)

Year	(a) Influent Mass Avg. mg/l	(a) Effluent Mass Avg. mg/l	(b) Conc. Reduction %	(c) Gross Removed %	(d) Net Removed %	Wastewater Added 1000 cu m
Total Dissolved Phosphorus						
1976	2.40	0.09	96	91	94	66.9
1977	3.48	0.11	97	88	92	134.8
1978	2.45	0.16	94	72	77	118.7
Dissolved Nitrogen						
1976	3.80	0.58	85	75	75	66.9
1977	4.95	0.46	91	80	92	134.8
1978	10.84	0.61	94	80	85	118.7

(a) Mass average concentrations are weighted by the actual amount of water entering or leaving the wetland.
(b) Concentration reductions are based on mass average concentrations.
(c) Gross removals are based on total inputs and outputs.
(d) Net removals are based on inputs and outputs less background value for the wetland.

Mudroch and Capobianco (Reference 22) describe studies done on Cootes Paradise's feeder streams and marshes. Poor quality treated wastewater of an unstated volume from the town of Dundas, Canada, enters the marsh. The 520 ha (1300 acres) wetland has received this discharge since 1919. Nutrients, productivity and heavy metals in vegetation and sediments were studied. Tables 12 and 13 report metal and nutrient levels in selected plants. Sediments show increased levels in lead,

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Table 12. MACRONUTRIENT CONTENT OF GLYCERIA GRANDIS BIOMASS ABOVE GROUND, COOTES PARADISE MARSH, CANADA (Reference 22)

	P		K		N		Ca		Mg	
	%	g/m^2	%	g/m^2	%	g/m^2	%	g/m^2	%	g/m^2
Locality	**April**									
West Pond	0.51	3.1	1.80	10.8	3.2	19.2	0.57	3.4	0.22	1.3
Long Valley	0.40	2.0	2.20	11.0	2.20	11.0	0.32	1.6	0.16	0.8
Desjardines Canal	0.34	1.7	2.30	11.5	2.00	10.0	0.70	3.5	0.24	1.2
	June									
West Pond	0.13	6.2	1.40	67.2	1.50	72.0	0.50	24.0	0.18	8.6
Long Valley	0.21	6.8	1.80	48.6	1.70	45.9	0.40	10.8	0.24	6.4
Desjardines Canal	0.13	5.2	1.20	48.0	1.50	60.0	0.70	28.0	0.20	8.4

Note: percent by dry weight

Table 13. UPTAKE OF METALS BY PLANTS, COOTES PARADISE MARSH, CANADA (Reference 22)

Species and Location	Month	Uptake (ppm dry weight)			
		Pb	Zn	Cr	Cd
Lemna minor West Pond	April	210.0	150.0	35.0	5.0
	July	190.0	165.0	40.0	3.0
Lemna minor North Shore	April	30.0	55.0	18.0	<1.0
	July	28.0	60.0	23.0	<1.0
Myriophyllum vert West Pond	April	30.0	40.0	25.0	2.0
	July	45.0	36.0	40.0	1.5
Myriophyllum vert North Shore	April	20.0	30.0	12.0	<1.0
	July	26.0	25.0	8.0	<1.0
Glyceria grandis West Pond	April	5.0	15.0	2.0	<1.0
	July	3.5	17.0	2.5	<1.0
Glyceria grandis Desjardins	April	4.5	18.0	3.5	<1.0
	July	5.1	14.0	2.5	<1.0
Glyceria grandis Long Valley	April	4.8	15.0	2.0	<1.0
	July	5.0	14.0	2.5	<1.0

chromium, nickel, copper and zinc. An elevated level of nitrogen, phosphorus and organic carbon was found in the top 5 cm of the bottom sediments. The authors conclude that the metals found in the vegetation were extracted from the sediments, which has been accumulating the metals since 1919, not the water column.

Fritz and Helle (Reference 12) have reviewed investigations done on cypress strands and domes at the Center for Wetlands of the University of Florida. Domes near the Whitney Mobile Home Park receive 2.5 cm per week of secondary effluent and a 24 ha portion of a very large strand receives 450 cu m/day (0.12 mgd) primary effluent from the town of Waldo, Florida. Removal of nutrients, biochemical oxygen demand (BOD_5), suspended solids, bacteria and heavy metals is accomplished by these cypress wetlands. Table 14 contains nitrogen, phosphorus and BOD_5 data. The vegetation in the dome and the sediments act as sinks for heavy metals; concentrations in dome waters are 2-3 times the influent. Trees grew 2.6 times faster in the dome after the secondary effluent was applied than before. The aquatic invertebrates and amphibians populations have decreased with the effluent's introduction. Fecal coliforms are completely removed by the domes. The survival and transmission of viruses in the effluent as it passes through the cypress dome is presently being studied.

Table 14. CYPRESS DOME WATER QUALITY, WHITNEY MOBILE HOME PARK, FL (Reference 12)

Criteria	Secondary Effluent	Dome Waters	Ground-Waters
BOD_5 (mg/l)	About 40	About 20	-
Nitrogen (mg-N/l)	8 - 15	8 - 15	0.1 - 2.5
Phosphorus (mg/l)	8 - 13	8 - 13	0.05- 2.0

Reedy Creek Utilities serves Walt Disney World in Orlando, Florida (Reference 20). A mixed hardwood swamp of 41 ha has been used to provide advanced secondary treatment and nitrogen removal to an average of 7570 cu m/day (2 mgd) of secondary effluent since July 1977. The bermed wetland area consists of a thick understory (low to the ground growth, e.g. grasses, ferns) of vegetation and pine, cypress, and bay trees. A 91 cm diamater pipe introduces the secondary effluent to the wetland and the final discharge is through a 6 meter rectangular weir after which the water flows ultimately to Reedy Creek. Biochemical oxygen demand, suspended solids, and total nitrogen average 1 to 1.5 mg/l in the final effluent. Dissolved oxygen is 1 to 2 mg/l in the final effluent. Color level is high due to dissolved tannic acids from the decomposing organic matter. Phosphorus may be diluted during periods of high flow because of rain.

The town of Jasper, Florida, has discharged approximately 1136 cu m/day (0.30 mgd) of wastewater into a very long cypress strand for sixty years. Starting in 1920 the town discharged raw wastewater, in 1950 they upgraded to primary treatment and since 1972 they have been discharging secondary effluent. A 28 ha section of this strand is being studied by Fritz and Helle (personal communication) of Boyle Engineers. The study is to determine appropriate loading rates for strand treatment. This study is being accomplished under the sponsorship of the National Science Foundation and will be completed in 1981.

Full Scale Artificial Wetland Projects

Sutherland and Bevis (Reference 29) have studied a seepage (non-discharging) cattail wetlands of 465 ha which receives 643 cu m/day (0.17 mgd) secondary effluent between June and October, from the Town of Vermontville, Michigan. Water quality, flora and fauna have been studied. Table 15 summarizes water quality results. Vegetation biomass was measured in standing crop, and nutrients levels in pounds per acre contained in plant tissues were calculated. The amounts of total phosphorus and total Kjeldahl nitrogen decreased in successive units within the treatment train.

Demgen (Reference 8) and Bogaert et. al. (Reference 1) studied an 8.1 ha (20 acres) marsh/pond wetland system at Mt. View Sanitary District, in Contra Costa County, California. The system has received 3028 cu m/day (0.8 mgd) of secondary effluent in six years. The goals of the system are both wildlife habitat and effluent polishing. Water quality, biomass, floral and faunal communities, and productivity have been researched. The artifical wetland supports 72 species of plants, 22 species of animals, 90 species of birds, and 34 species of aquatic invertebrates. Maximum standing crop biomass of *Typha latifolia* (cattail) and *Scirpus californicus* (bulrush) have been determined to be (as dry weight) 1872 g/sq m and 10,896 g/sq m, respectively. Table 16 lists water quality data. There are seasonal variations which are not reflected in these three-year averages. The additions of suspended solids and biochemical oxygen demand are due primarily to algae growth.

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Table 15. **WATER QUALITY IN SEEPAGE WETLANDS, VERMONTVILLE, MICHIGAN (mg/l)** (Reference 29)

Criteria	Influent	Ponds	Wetland Fields	Episodic Overflow	Groundwater
Chlorides	280	207	157	123	124
Ammonia-Nitrogen	37	2.5	2.0	—	0.7
Nitrate-Nitrogen	1.3	1.0	1.2	—	1.4
Total Kjeldahl Nitrogen	81	6.5	5.0	—	3.7
Phosphorus	5.3	1.8	2.1	0.64	0.04
BOD$_5$	—	—	—	5.5	—
Suspended Solids	—	—	—	20	—

The Village of Neshaminy Falls, Pennsylvania, monitors their marsh/pond/meadow treatment system to comply with NPDES permit requirements. The monitoring began in May 1979 for standard water quality parameters. The system has been in continuous operation and has a final discharge. Tables 17 and 18 contain data showing levels of and removal rates for various water quality parameters through each segment of the system. The average daily level in the final effluent of dissolved oxygen for 1980 was 6.7 mg/l and for pH 7.5 units (personal communication).

Table 19 contains a summary of the nutrient removal efficiencies achieved by full-scale wetland projects.

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Table 16. MT. VIEW SANITARY DISTRICT WETLAND WATER QUALITY DATA, 1975-1978 (AVERAGES) (Reference 1)

Criteria	Influent (mg/l)	Wetland Discharge 1* (mg/l)	Wetland Discharge 2* (mg/l)	Percent Removal W.D.1	Percent Removal W.D.2
Nitrate Nitrogen	7.4	3.3	1.7	56	77
Ammonia Nitrogen	7.9	6.7	6.8	15	14
Organic Nitrogen	4.8	4.4	4.6	8	4
Phosphate Phosphorus	9.9	9.1	10	0.1	+1
Refractory Organics**	50	33	36	34	28
BOD_5	23	24	15	+4	35
Suspended Solids	20	47	33	+135	+65

* See Figure 4, page 30 for location of Wetland Discharge 1 and 2 (W.D.1 and W.D.2).

** Data represent only a one-year study

Table 17. NESHAMINY FALLS OPERATIONAL RESULTS, WATER QUALITY

Parameter	Number of months sampled	Average mg/l: Raw Influent	Average mg/l: Aeration Lagoon Effluent	Average mg/l: Marsh Effluent	Average mg/l: Pond Effluent	Average mg/l: Final Effluent
BOD	12	160	79	41	18	7
SS	20	171	182	45	27	11
Ammonia-N	20	24	9	6	5	3
Nitrate-N	20	0.6	14	4	3	2
Total-P	15	8	8	3	2	2

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Table 18. **NESHAMINY FALLS REMOVAL RATES**

Parameter	Percent Removal By Aeration Lagoon	By Marsh	By Pond	By Meadow	Total
BOD	51	24	14	7	96
SS	6 increase	80	11	9	94
Ammonia-N	63	12	4	8	87
Total-P	0	63	12	0	75

DESIGN DATA FROM FULL SCALE WETLAND FACILITIES

A complete list of the full-scale wetland projects identified for this assessment is given in Table 20. Available design data is summarized in Table 21 for each of the projects and expanded descriptions follow for selected projects. Six of the projects are briefly discussed including three natural and three artificial treatment systems. The physical process, design criteria, and equipment utilized in each project are presented. Surface loading rates shown may be conservative due to the availability of large tracts of marshes in some areas of the country. The pilot projects now underway in Arcata, California. Ontario, Canada and other areas will be valuable in defining loading rates.

The Houghton Lake (Reference 16) peatland receives secondary treated, dechlorinated domestic wastewater. The wastewater is pumped through an underground force main from the treatment plant to the edge of the peatland. At that point the pipeline surfaces and runs along a raised platform about 762 meters into the wetland. A second gated line, 975 meters long, runs perpendicular. The water is evenly distributed over the surface of the peatland through 100 gates which discharge approximately 60 liters/minute (16 gpm). Over 227,700 cu m (60 mg) in 1978 and 3,875,000 cu m (100 mg) in 1979 were discharged to the wetland during the summer months. Surface water depths are 2 to 8 cm and the water flows across the peatland to the lake.

Table 19. SUMMARY OF NUTRIENT REMOVAL DATA FROM FULL SCALE WETLAND

Project	Flow m^3/day	Wetland Type	Percent Reduction			
			TDP[a]	NH_3-N[b]	Nitrate	TN[c]
		Natural Wetland				
Brillion Marsh, Wisconsin	757	Marsh	13	—	51	—
Houghton Lake, Michigan	379	Peatland	95	71	99[d]	—
Wildwood, Florida	946	Swamp/Marsh	98	—	—	90
Concord, Massachusetts	2309	Marsh	47	58	20	—
Bellaire, Michigan	1136[e]	Peatland	88	—	—	84
Cootes Paradise, Town of Dundas Ontario, Canada	—	Marsh	80	—	—	60-70
Whitney Mobile Home Park, Florida	approx. 227	Cypress Dome	91	—	—	89
		Artificial Wetland				
Vermontville, Michigan	643[f]	Seepage Marsh	95	72	Increased	—
Mt. View Sanitary District, California	3028	Marsh/Pond	0	14	67	—
Village of NeshaminyFalls, Pennsylvania	114	Marsh/Pond/Meadow	75	87	Increased	—

a) Total dissolved phosphorus
b) Ammonia nitrogen
c) Total nitrogen
d) Nitrate + Nitrite
e) May-November only
f) June-October only

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TABLE 20. FULL SCALE WETLAND SYSTEMS IN THE UNITED STATES

Project	Wetlands Type	Influent Type^a	Wetland Area (ha)	Average Dry Weather Flow (m^3/day)
	Natural Wetlands			
City of Brillion, Wisconsin	Marsh	3	1619*	757
Houghton Lake Sewer Authority, Mich.	Peatland	3	243^b	379
Whitney Mobile Home Park, Florida	Cypress dome	3	6*	227*
City of Wildwood, Florida	Swamp	2	202	946
City of Waldo, Florida	Cypress strand	2	160^c*	454
Town of Drummond, Wisconsin	Bog	3	10	379
Town of Concord, Massachusetts	Shrub, deep marsh	3	19	2,309
Hamilton Township, New Jersey	Freshwater tidal marsh	3	500	26,495
Town of Dundas, Ontario, Canada	Marsh	2	520	--
Village of Bellaire, Michigan	Forested	3	15	1,136^d
Reedy Creek Utilities, Florida	Swamp	3	41	7,570
	Artificial Wetlands			
Vermontville, Michigan	Cattail Marsh	3	4.65	643^e
Mt. View Sanitary District, Calif.	Marsh/pond	3	8.10	3,028
East Lansing, Michigan	Marsh/pond	3	15.80	1,892-3,785
Neshaminy Falls, Pennsylvania	Marsh/pond/meadow	1	0.60	114

a) Influent Types: 1. Aerated Raw Sewage; 2. Primary Effluent; 3. Secondary effluent
b) Effective removal area 3 ha
c) Effective treatment is achieved within 4 ha, but the total stand is approximately 160 ha.
d) May-November only
e) June-October only

*Approximately.

TABLE 21. DESIGN DATA FOR FULL-SCALE FACILITIES -- NATURAL WETLAND

Design Criteria	Brillion Wisconsin	Houghton Lake Michigan	Whitney Park Florida	Wildwood Florida	Drummond Wisconsin
Wetland Type	Marsh	Peatland	Cypress/Duckweed	Swamp	Bog
Wetland Area (ha)	1619^{a} 156^{b}	243^{a} 2^{b}	6	202	24
Depth	Variable up to 1.5 m	2-8 cm	Variable^{c}	--	20 cm
Substrate	Native soil	peat and clay	organic muck and sandy clay	Underlaid by native clay	Native clay up to 11 m organic matter.
Flow (m^{3}/day)	733-1533	379	approx. 227	946	379
Inlet structure	Stream^{d}	Gated aluminum irrigation pipe	Standpipe	Diversion ditch	Gated irrigation pipe
Surface loading ha/1000 m^{3}/day	101-212^{b}	5.3^{b}	26.4	214	63
Energy: Pumping Requirements					
To System	--	Yes	Yes	No	No
Within System	No	No	No	No	No

a) Total marsh area
b) Study area
c) Depth kept below top of cypress knees
d) Treated effluent is discharged to stream above marsh

(Continued)

Table 21.Continued

Design Criteria	Concord Massachusetts	Hamilton Marsh New Jersey	Dundas Ontario	Bellaire Michigan	Reedy Creek Florida
Wetland type	Shrub/deep marsh	Ponds/marshes	Marsh	Forested peatland	Swamp
Wetland area (ha)	19	500	520	15	41
Depth	--	Tidal	Variable up to 0.5 m	Few inches variable	Variable up to 1 meter
Substrates	--	Organic silt silt-clay	Sand, silty clay, peat	Peat	Native soils, muck
Flow (m^3/day)	2,309	26,495[e]	--	1,136[f]	7,570
Inlet structure	46 cm discharge pipe	Direct discharge to tributary creek	--	3-4 pipe discharges	91 cm discharge pipe
Surface Loading ha/1,000 m^3/day	8.2	1.9	--	13.2	5.4
Energy:					
Pumping Requirements					
To System	No	No	--	No	No
Within System	No	No	No	No	No

e) Hamilton Marsh also received flow from other local streams in addition to the sewage effluent.
f) May-November only.

(Continued)

Table 21. Continued

	ARTIFICIAL WETLAND		
Design Criteria	Vermontville Michigan	Mt. View Sanitary District, Calif.	Neshaminy Falls Pennsyvlania
Wetland Type	Cattail marsh	Marsh/ponds	Marsh/pond/meadow
Wetlands Area (ha)	4.7	8.1	0.6
Depth (cm)	15	15-90	--
Substrate	Clayey-silt	Native clay	Native clay mixed with Bentonite and compacted
Flow (m^3/day)	643 June-Oct only	3028	114
Inlet Structure	Multiple outlet manifold pipe	Weir	Overflow weirs
Surface loading ha/1000 m^3/day	7.3	2.7	5.3
Energy: Pumping Requirements			
To System	No	No	No
Within System	No	No	No

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In the Whitney Mobile Home Park Project (Reference 12), there are three process options utilizing cypress wetland for tertiary treatment. A dome is utilized in its natural state and receives secondary effluent via a force main which extends underground to the edge of the dome and then lays on top of the organic layer inside the dome. The water is introduced to the dome through a standpipe, so as not to disturb the organic layer. The ponded wastewater percolates through the organic muck and underlying sandy clay to the groundwater. There is also an occasional spillover when the dome's basin becomes overloaded due to surface runoff. The isolated dome process is the same as the natural dome except that it avoids this overflow problem. An earthen dike is constructed around the perimeter of the dome excluding any surface runoff. The third type of cypress wetland is a strand. Secondary effluent is introduced through a multiple inlet pipe along the upper end of the strand and is conveyed in a sheet flow through it. Strands may be up to several miles in length. The water passes through various vegetation types: cypress, mixed hardwood, and marshes. There may be channels and also ponded areas with floating vegetation. It is a flow-through system.

The Hamilton Marsh treatment system (Reference 35) has a simple process scheme. The treated effluent is discharged to Crosswicks Creek above the marsh at a rate of 26,495 cu m/day (7 mgd). The effluent flows, with the water, to the marsh where it passes through a number of habitat types -- streams, high marsh, ponded areas that drain, and continuously wet areas. There is a diversity of grasses and broad-leafed plants. The flow is affected by the tides and eventually reaches the Delaware River. No hardware is involved in this system.

The Vermontville, Michigan seepage wetland treatment system (References 29 and 37) has been in operation since 1971. The raw domestic wastewater is pretreated using a stabilization pond. The water is then conveyed by gravity through a 10-inch main and 8-inch manifold pipes having several outlets in each of the three fields. Wastewater effluent is applied for 3-4 hours a day, 5 days a week from June to October. The water is contained within these cattail wetlands until it seeps through the soils to the lower plot. During heavy rains there is also surface overflow from these upper wetlands to the lower plots. The lower wetland normally only receives seepage and has a surface discharge to a stream. Figure 3 shows the flow pattern utilized in the Vermontville system.

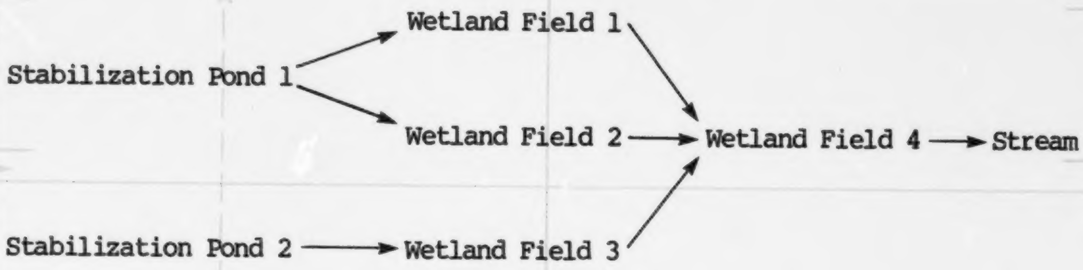
Wetland Field 1
Stabilization Pond 1
Wetland Field 2
Wetland Field 4
Stream
Stabilization Pond 2
Wetland Field 3

Figure 3. **Vermontville Michigan Seepage Wetland Process Flow Diagram.**

The Mt. View Sanitary District near Martinez, California (Reference 7 and 8) has operated a system receiving 3,028 cu m/day (0.8 mgd) of secondary treated domestic wastewater for six years. The flow is by gravity and over weirs throughout the system. Figure 4 shows the flow patterns.

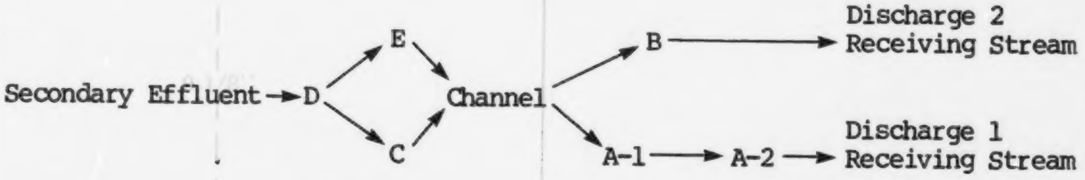
Discharge 2
E
B
Receiving Stream
Secondary Effluent
D
Channel
Discharge 1
C
A-1
A-2
Receiving Stream

Figure 4. **Mt. View Sanitary District Wetland Process Flow Diagram.**

Plot D is channelized by levees with some growth of emergent vegetation, primarily Typha. Plot E is open water with islands, and Plot C is used seasonally for the growth of grasses for migratory waterfowl food. Plots A-1 and B contain a high proportion of emergents, relative to surface area, approximately 90 and 75 percent, respectively. Plot A-2 is open water with artificial substrates in place of emergent vegetation and wind-operated circulators. The artificial substrates are constructed of redwood bark to provide surface area for colonization by aquatic invertebrates and bacteria. There is a continuous discharge from Plots A-2 and B.

Approximately 60 percent of the surface area is open water allowing summer growth of algae. This creates large differences in the discharge water quality. For example, the four-year average effluent suspended solids concentration in the winter was 24 mg/l while the summer average was 54 mg/l.

The Village of Neshaminy Falls, Pennsylvania utilizes a 0.6 ha meadow/pond/marsh system for its total domestic wastewater treatment needs. The 114 cu m/day flow is comminuted, mechanically aerated, and flows to four parallel marsh plots, each 613 m^2. The plots are sealed, filled with sand and planted with cattails. The water passes through the root zone and overflows to a two-meter deep facultative pond. After a 16-day detention time, the water passes on to four parallel meadows, 306 sq m each in area, which are planted with reed canary grass. The final effluent is chlorinated and discharged into Little Neshaminy Creek.

A partial list of full-scale projects presently in the design phase is found in Table 22.

AVAILABLE EQUIPMENT AND HARDWARE

Products and suppliers of various equipment used in the operation of various wetland systems are found in Table 23.

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TABLE 22. PARTIAL LIST OF FULL-SCALE PROJECTS IN THE DESIGN PHASE (March 1982)

Location	Contact	Wetland Type	Project Description
Black Diamond Washington	Rick Esvelt Kramer, Chin & Mayo Seattle, WA (206) 447-5359	Natural: Peat bog overlain by willows and dense swamp plants	Nutrient removal from 1,250 m^3/day (0.33 mgd, annual average year 2000) will be accomplished by the 46.5 ha (115 acre) swamp. Begin construction 1981.
Vernon Township New Jersey	James Hinckley Consultant 25 Railroad Avenue Warwick, NY 10990 (914) 986-3001	Artificial meadow/marsh/pond	System to treat wastewater from a single townhouse development, design flow 151 m^3/day (40,000 gpd). Two-thirds is secondary effluent, and one-third is raw sewage. Begin construction 1981.
Brookhaven New York	Maxwell Small Maxec, Inc. Bellport, NY (516) 286-8886	Artificial marsh/pond	System being designed to treat scavenger waste and leachate from a landfill.
Eureka California	Francesca Demgen Demgen Aquatic Biology Vallejo, CA (707) 643-5889	Artifical marsh	Marsh is specifically for habitat creation. However, water quality data will be collected and O&M data will also be valuable. Marsh to receive secondary effluent. Begin construction 1982.

(Continued)

TABLE 22. Continued

Location	Contact	Wetland Type	Project Description
Savannah River area between Savannah and Augusta, GA	M. Kristine Butera National Aeronics & Space Administration Mississippi (601) 688-3830	Natural	This is a survey incorporating Landsat (satellite) technology for identification of and assessment of wetlands for waste assimilation.
Norwalk Iowa	Pete Hodap Engineers Assoc. Fort Dodge, IA (515) 576-7686	Artificial	A waste stabilization lagoon and borrow area, total 13 ha, will be converted into an artificial wetland by seeding cattail and bulrush. The system will receive 2385 m^3/day of secondary effluent.

Table 23. **WASTEWATER WETLAND EQUIPMENT SUPPLIERS**

Product	Description	Supplier
Wetland Vegetation	Seeds and Rootstock	Kester's Wild Game Food Nurseries, Inc. P.O. Box V Omro, WI 54963 414/685-2929
Wetland Vegetation	Seeds and Rootstock	Wildlife Nurseries P.O. Box 2724 Oskosh, WI 54903 414/231-3780
Ecofloats	Artificial Aquatic Invertebrate Habitat	EBC Company 222 Franklin Avenue Willits, CA 94590 707/459-6201
Windecos	Unit combining ecofloats and wind driven circulator	EBC Company (see above)
Aquascreen[a]	Screen for vegetation control	Menardi-Southern Corp. 3908 Colgate Houston, TX 77087 713/643-6513

a) Aquascreen is not currently in use in wastewater wetlands, but is used in other aquatic habitats. It has potential for use to control vegetation growth in critical areas.

Other Notes

1. Most equipment utilized in wastewater wetlands is standard and suppliers will not be listed.
2. Construction of a wetlands may entail some unique problems. A lightweight, wide track "Mud-Cat" bulldozer can be particularly useful on soft soils.

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SECTION 4

TECHNOLOGY EVALUATION

PROCESS THEORY

Introduction

The components of the wetland system which perform the wastewater treatment are: algae, macrophytes (larger, rooted plants), bacteria, zooplankton, and the substrate (bottom soils). These components may be present in both natural and artificial wetlands and no differentiation between these two system types will be recognized in this section. The following discussion of process theory will be subdivided into two sections; the individual wetland components, and the removal mechanisms for specific pollutants.

Wetland Components

The major system components affecting treatment of the wastewater are: plants, soils, bacteria and animals. Also influencing the treatment process are environmental conditions such as pH, temperature, water depth, and dissolved oxygen. Each removal process requires specific conditions and the conduct of the process often induces changes in the original conditions.

Plants--

The plant species present in a wetland system will vary with the wetlands location and type. Table 24 lists some dominant species in various wetland types. A wetlands system will support the growth of a great variety of plant species, the composition of which may change seasonally and over time. The vegetation in wastewater wetlands experiences high levels of productivity. Plants growing closest to the wastewater influent point often have elevated levels of chlorophyll a. Plants, particularly algae, contribute oxygen to the water and macrophytes influence evapotranspiration rates. This water loss can be considerable in certain climates. Upon being harvested, plants may be used for mulch, fertilizer, feeds, or may be anaerobically digested to produce methane gas.

TABLE 24. DOMINANT WETLAND PLANTS

Wetland Type	Dominant Vegetation Latin Name	Common Name
Marsh	*Phragmites*	Reeds
	Typha spp.	Cattails
	Scirpus spp.	Bulrushes
Cypress Dome	*Taxodium* spp.	Cypress tree
	Lemna spp.	Duckweed
Peatland	*Carex* spp.	Sedge
	Salix spp.	Willow
	Chamae daphne calyculata	Leatherleaf
	Betula pumila	Bog Birch

Soils--

Wetland soils and sediment types are extremely variable. Often, natural wetlands are underlain by a clay layer which provides a natural seal. The sediments play a key role in pollutant removal by supplying absorption sites for many chemical constituents. Increased levels of clay particles and organic matter in the sediments will allow increased absorption of heavy metals and phosphorus. Bacteria and organic matter will also collect on the sediment. This can create a layer where anaerobic reactions will take place. The soil types influence the amount of percolation in a non-sealed system. In addition, the soil type affects vegetation able to grow in the system.

Bacteria--

Bacteria serve to decompose organic matter and perform many of the steps in the nitrogen cycle. A multitude of bacterial species are present.

Animals--

In essence, the whole food web contributes to removal of pollutants in a wetlands treatment system. The larger animals provide a mechanism for complete removal of some constituents from the system. Zooplankton, the small free floating animals, feed on algae and clumps of bacteria. Some of the aquatic invertebrates also feed directly on this source and others ingest zooplankton. The invertebrates and wetland plants serve as food for a whole host of larger organisms: fish, birds, reptiles, mammals, and amphibians. Wastewater wetlands can be expected to attract many representatives of each animal category.

Removal Mechanisms

The pollutant parameters to be discussed in this section are: biochemical oxygen demand (BOD), suspended solids (SS), bacteria and viruses, phosphorus, nitrogen, heavy metals, and refractory organics.

Biochemical Oxygen Demand and Suspended Solids--

BOD and SS introduced to the wetlands ecosystem are removed through two basic processes. The long retention time and low velocities allow a portion of the BOD and SS associated with the heavier solids to physically settle and then decompose. The soluble portion and lighter solids that will not settle are metabolized by microorganisms within the water column and on the surface of vegetation. These microorganisms may include bacteria and zooplankton (cladocera, copepods and rotifers).

Bacteria and Virus--

More is understood about the removal mechanisms affecting bacteria than viruses. It is postulated that viruses are absorbed by the soil as the water seeps through the sandy clay soils under cypress domes. Viruses may also be deactivated during retention in the wetlands because they are away from a suitable host for too long. Bacteria are lost from the system by sedimentation, ultraviolet radiation, chemical reactions, natural dieoff and predation by zooplankton. Quantifying bacterial removal rates are difficult when coliforms are used as the test organism because animals living in the wetlands contribute coliforms.

Phosphorus--

In many cases the primary purpose of a wetlands treatment system is nutrient removal or conversion. The system's ability to meet this goal with respect to nitrogen is good, whereas phosphorus removal is more variable. In the cypress domes and Vermontville seepage wetland, removal rates are high due to the soil-water contact provided; the phosphorus is adsorbed onto the soil particles. Peat also has this capability. In wetlands where the water only contacts a few centimeters of substrate soils, the adsorption capacity is finite and may be reached within the first few years of operation, depending on the system size.

Plants supply other removal mechanisms. Duckweed, algae, cypress trees and emergent vegetation such as cattails and bulrushes all assimilate inorganic phosphorus. The roots and rhizomes of the plants extract the phosphorus from the water. Harvesting of the above ground vegetation biomass will generally only remove ten percent or less of the phosphorus applied to the system. Duckweed is an exception to this; when

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harvested it removes approximately two-thirds of the phosphorus applied. High winter flows may cause flushing of the system's phosphorus contained within dormant and decaying plant parts.

Chemical precipitation by complexing with metals such as iron and manganese is another method for phosphorus removal. These precipitates are formed at high pH levels and under aerobic conditions. They are released under low pH and anoxic conditions; therefore, removal of phosphorus by this mechanism may be temporary. It can be noted, however, that often the phosphorus is complexed during the growing season and is released during the winter. In this case the receiving body may not be as adversely affected by the phosphorus discharged as it might be in warmer months.

Nitrogen--

Nitrogen enters the wetlands in various forms: ammonia, organic-N, nitrite, and nitrate. In cypress domes, duckweed assimilates approximately one-half of the nitrogen applied. In other marshes, algae and macrophytes incorporate ammonia and nitrate. Much of this is a temporary form of removal unless the plants are harvested. Harvesting can generally remove up to only about 10 percent of the nitrogen added to the system. Nitrification and denitrification result through bacterial action. The former is accomplished in an aerobic atmosphere by bacteria living on submerged surfaces such as plants, sediments or artificial substrates. The end product of nitrification is nitrate. In denitrification the nitrate is converted to N_2O and N_2, gases which are lost to the atmosphere. This process generally occurs in the sediments under low dissolved oxygen or anaerobic conditions.

Volatilization provides another means of nitrogen removal from the system. In this process ammonia is lost to the atmosphere at a pH greater than 8. Due to the availability of nitrogen, fixation is not important in wastewater wetlands. The process which contributes most to nitrogen removal depends on the wetland's characteristics. For example, the Houghton Lake marsh was nutrient deficient prior to the introduction of effluent. Therefore, the plants provide a great deal of removal by assimilating the nitrogen. A different method dominates the Michigan State University ponds and wetlands. Here high algae productivity elevates the pH to a point such that volatilization takes place, thereby releasing ammonia to the air during the warm summer months.

Heavy Metals--

The four mechanisms for removal of heavy metals are 1) formation of insoluble precipitates, 2) adsorption, 3) ion exchange, and 4) assimilation. Insoluble precipitates of metals such as lead, zinc, chromium, cadmium, nickel and copper

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can be formed. These precipitates may be formed with sulfides, oxides, hydroxides, carbonates and phosphates. Adsorption and ion exchange of the metals onto clay particles and with organic compounds can occur. Bulrushes, reeds, cattails and duckweed all have varying abilities to directly assimilate heavy metals. These plants may concentrate the elements up to thousands of times greater than the level in the surrounding water without impairing their own functions. The variables affecting the rate of removal for heavy metals include: the organic content and cation exchange capacity of the wetland soil, salinity, temperature, pH, sediment type, and vegetation type.

Refractory Organics--

There is some evidence showing that refractory organics can be removed within wetland systems. Much study remains to be done. Evidence suggests that phenolic compounds, chlorinated hydrocarbons, organic hydrocarbons and petroleum compounds may be removed or broken down to some degree. The investigations point to three methods for removal. Phenols and perhaps other compounds can be metabolized by bulrushes to form amino acids and proteins. The second mechanism is adsorption to soil and plant surfaces and then chemical and bacterial decay. Table 25 contains a summary of these removal mechanisms.

Constituent Removal Efficiencies--

In reviewing the literature dealing with wetlands, a great deal of confusion exists in the reporting of performance data for natural and artificial systems used for the treatment of wastewater. Also, there is no standardization regarding the basis on which performance data are reported. For example, in some articles, performance data are reported as a function of time, while in others as a function of distance. Usually, no basis or information is given on how time or distance are interrelated. Further, the data for most of the natural systems are extremely site specific and should not be generalized.

Recognizing the above limitations, the reported ranges of removal for the constituents of concern in wastewater are presented in Table 26. From a review of the limited data presented in Table 26, it can be concluded that the performance of wetlands with respect to most wastewater constituents is not well defined. Further, the range of values reported in Table 26 is also of concern, especially the lower removal efficiencies.

TABLE 25. CONTAMINANT REMOVAL MECHANISMS IN AQUATIC SYSTEMS EMPLOYING PLANTS AND ANIMALS[a] (Reference 28)

Mechanism	Contaminant Affected[b]	Description
Physical		
Sedimentation	P - Settleable Solids S - Colloidal Solids I - BOD, Nitrogen, Phosphorus, Heavy Metals, Refractory Organics, Bacteria and Virus.	Gravity settling of solids (and constituent contaminants) in pond/marsh settings.
Filtration	S - Settleable Solids, Colloidal Solids	Particulates filtered mechanically as water passes through substrate, root masses, or fish.
Adsorption	S - Colloidal Solids	Interparticle attractive force (van der Waals force).
Chemical		
Precipitation	P - Phosphorus, Heavy Metals	Formation of or co-precipitation with insoluble compounds.
Adsorption	P - Phosphorus, Heavy Metals S - Refractory Organics	Adsorption on substrate and plant surface.
Decomposition	P -Refractory Organics	Decomposition or alteration of less stable compounds by phenomena such as UV irradiation, oxidation, and reduction

(Continued)

TABLE 25. (Continued)

Mechanism	Contaminant Affected[b]	Description
Biological		
Bacterial Metabolism[c]	P - Colloidal Solids, BOD, Nitrogen, Refractory Organics	Removal of colloidal solids and soluble organics by suspended, benthic, and plant-supported bacteria. Bacterial nitrification/denitrification.
Plant Metabolism[c]	S - Refractory Organics, Bacteria and Virus	Uptake and metabolism of organics by plants. Root excretions may be toxic to organismis of enteric origin.
Plant Absorption	S - Nitrogen, Phosphorus, Heavy Metals, Refractory Organics	Under proper conditions, significant quantities of these contaminants will be taken up by plants.
Natural Die-Off	P - Bacteria and Virus	Natural decay of organisms in an unfavorable environment.

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[a] Stowell, et al. Toward the Rational Design of Aquatic Treatment Systems. University of California, Davis, 1980.

[b] P = primary effect; S = secondary effect; I = Incidental effect (effect occurring incidental to removal of another contaminant).

[c] The term metabolism includes both biosynthesis and catabolic reactions.

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TABLE 26. REPORTED RANGES OF REMOVAL EFFICIENCY FOR WASTEWATER CONSTITUENTS IN WASTEWATER IN NATURAL AND ARTIFICIAL WETLAND (Based on Reference 31)

Constituent	Removal Efficiency, % Natural Wetland Primary Treatment		Artificial Wetland Primary Treatment	
	Primary Treatment	Secondary Treatment	Primary Treatment	Secondary Treatment
Total solids		40-75		
Dissolved solids		5-20		
Suspended solids		30-90		
BOD_5		70-96	50-90	0-48
TOC		50-90		
COD		50-80	50-90	
Nitrogen (total as N)	90	40-90	30-98	
Phosphorus (total as P)	84	10-61	20-90	0-60
Refractory organics				28-34
Heavy metals[a]		20-100		
Pathogens				

[a] Removal efficiency varies with each metal.

PROCESS CAPABILITIES AND LIMITATIONS

Like all wastewater treatment systems, wetland have specific capabilities and limitations. Some of these capabilities or advantages include the following:

- Performance of the system is heavily dependent on the proliferation of plants. These plants presently exist in many areas of the country, allowing utilization of wetlands nationwide.
- Operation and maintenance costs are generally well below those of conventional treatment systems.

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- Wetland can provide benefits in addition to wastewater treatment, such as wildlife habitat, open space, recreation, education, and stream flow augmentation.

- Treated effluent from the wetlands can be available for reuse and may be highly compatible for projects involving aquaculture and silviculture.

- Many categories of pollutants are treated within a single system.

- The treatment mechanisms (particularly the soil and vegetation) are relatively stable, allowing the system to withstand shock loadings.

Some of the limitations or disadvantages of wetland treatment systems include the following:

- The amount of land required may prohibit their use in highly urban areas.

- The treatment process efficiencies are not completely defined, making precise design criteria difficult to establish.

- The wetland plant species vary in their requirements and may be limited by physical conditions such as sunshine, temperature, and water depth.

- There is a possibility of vector breeding and pathogen transmission.

- Potential institutional problems may exist relating to obtaining discharge permits.

FULL SCALE DESIGN CONSIDERATIONS

Introduction

Specific design criteria for developing wetland wastewater treatment systems are limited compared with conventional wastewater treatment processes. In wetlands systems, removal efficiencies are a function of naturally occurring parameters which cannot be easily controlled, such as temperature, sunlight, and native plant species. This is unlike the flexibility enjoyed in operating a conventional treatment plant. This difference is one of the reasons that the design approach for wetlands is much different than for that of conventional plants. Wetlands technology does not lend itself to conventional design criteria. This section will include information applicable to all types of systems with subsections for specific wetland variations. Site specific information on sizing of pumps, distribution lines, inlet and outlet structures will not be included.

Wetland Treatment System Design

There are several basic steps to be considered when developing a preliminary design for a wetland treatment system. Table 27 lists these steps and is followed by a discussion of each one.

TABLE 27. WETLAND DESIGN METHODOLOGY

1. Establish treatment goals based on:
   a. Waste discharge requirements.
   b. Reuse potential or concurrent beneficial use.
2. Evaluate land availability.
   a. Existing wetland.
   b. Selection of wetland types suitable with available land.
3. Analysis of local conditions.
   a. Water budgeting and application method.
   b. Soils analysis.
4. Determine hydraulic loading and application method.
5. Select vegetation.
6. Design levees.
7. Design of distribution system to insure good circulation.

The first step in designing a wetland wastewater treatment system is to establish treatment goals. The applicable waste discharge requirements should be reviewed to determine the level of treatment which is necessary. The possibility of reuse of the wetland effluent should be considered as well as concurrent beneficial uses of the wetland itself. Examples of concurrent beneficial uses include: wildlife habitat, education, recreation, aquaculture, irrigation and growing vegetation for fuel for methane production.

Areas within an economically feasible radius of the wastewater source should be surveyed to determine the availability of natural wetlands or land for creation of an artificial wetland. In choosing a natural system, the designer must assess the existing uses of the wetland and the potential environmental impacts of applying treated wastewater. If an artificial system is to be designed then the type of system must be chosen: marsh, marsh-pond, seepage wetland, or lined/vegetation trenches, etc. This decision is based upon the availability and suitability of the land.

The third step is to complete a water budget by analyzing available wastewater flow, other possible inflows, precipitation, percolation and evapotranspiration. Soils analyses are necessary to assess the infiltration rate, suitability for growing wetland vegetation, soil salinity, and amount of clays and organic matter which will affect adsorption capacity. The level of the groundwater table should be established and a determination made as to whether the effluent will reach the groundwater.

The results of the water budget allow calculation of loading rates and total area requirements. Hydraulic loading rates investigated or in use vary from 850 hectares per million cubic meters of wastewater (8 acres/mgd) to hundreds of thousands of hectares; therefore, practical considerations such as available land area can influence the rate chosen. The operating regime also may influence the land area required. The wetlands may receive effluent year round or seasonally. Wastewater may be applied on a continual or a batch basis with a point or non-point discharge. Temperature restrictions affecting growth of vegetation, bacteria and other wetland organisms will affect application rate and total area required.

In a natural wetland vegetation will already be present. Some changes in species may be induced by the application of wastewater. In an artificial wetland, vegetation will need to be established. Vegetation selection is a key component in design of an artificial system. The vegetation chosen will have depth tolerance limits which should be incorporated into the hydraulic scheme. Local varieties of cattail, bulrushes, reeds, and other emergents will be the most desirable. Some may be planted by seed or rootstock and the others allowed to colonize naturally. Care should be taken when selecting exotic (non-native) species. These non-natives could be detrimental to the local environment beyond the bounds of the treatment wetlands. By choosing native varieties of plants the designer will be assured that they are compatible with local weather conditions. Vegetation should be planted in spring or early summer and a full year allocated for start-up. A variety of vegetation will usually become established in a stable environment.

Many wetland treatment systems incorporate levees within the design. These levees should have steep side slopes, usually 2:1, consistent with the soil characteristics. They should be compacted and have two feet of freeboard. Top widths should be eight to twelve feet and able to support a maintenance vehicle. It is important to establish such access routes. For bogs and cypress domes, boardwalks in lieu of levees may be a more appropriate means of gaining access. Vegetation will provide adequate erosion control except where heavy stress conditions exist, such as around flow structures. In these places additional erosion control measures should be taken. The wetland treatment system perimeter may need to be diked and perhaps fenced with a buffer zone between the treatment system and non-treatment wetlands.

The necessity of maintaining adequate circulation is common to most of the wetland types except possibly cypress domes. Influent and effluent structures should be placed so as to avoid short circuiting. Multiple inlet structures may be advisable. The effect of the prevailing winds should be considered. Natural and artificial islands, ditches and baffles can also be used to influence flow patterns. The goals in establishing good circulation are avoidance of stagnation and short circuiting, and promotion of maximum vegetation/water contact. The depth in most systems varies from 15 to 60 cm. This allows good colonization by vegetation. In natural wetlands, such as bogs and other peatlands, the vegetation may be several feet thick, although no open water is present.

Specific Wetland Types

Man-made and natural wetlands have both been used for wastewater treatment. Man-made or artificial wetlands have been designed to be similar in appearance and species composition to natural wetlands. Marsh, marsh/pond and seepage wetlands systems are in this category. Lined/vegetated trenches are not of this type since each trench employs a monoculture of vegetation and the system is not contiguous with the surrounding environment. Natural wetland systems that have been used in wastewater treatment include marshes, cypress domes and strands, bogs and peatlands.

Artificial Marsh--

Marshes may be located on historic tidelands, adjacent to rivers or lakes, or completely removed from an existing body of water. The artificial wetlands generally should be subdivided into cells. The number of cells and their size depends on the total project size and treatment objectives. Sufficient flow structures should be designed into the system to provide for alternate flow paths; flexibility is important. The depth range is usually from 15 cm to 1 m.

Marsh/Pond--

The marsh/pond system is a combination of marsh areas and shallow ponds. The ponds may have submerged vegetation, artificial substrates or be totally open water. The artificial substrates become colonized by bacteria, algae and aquatic invertebrates, thus serving as a partial substitute for emergent vegetation in an open water environment. If the wastewater is expected to have a high solids load it may be beneficial to excavate a deep area close to the inlet to enhance settling. This area could then be periodically dredged to remove any excess build-up of solids.

Lined/Vegetated Trenches--

Artificial wetlands can also be constructed in the form of long, narrow trenches lined with clay or artifical membrane and covered by gravel. Usually a single species of emergent vegetation is planted in the trench (monoculture). The water flows through the gravel-root zone.

Seepage Wetlands--

Seepage wetlands may be constructed on a number of soil types. Table 28 lists the unified soil classes which have been recommended as acceptable for establishing seepage wetlands. Siltiness is a general indication of suitability. Most soils within the five more suitable classes (ASTM standards) -- GM, SM, SC, OL, and MH -- contain a significant portion of silt. Mixtures of the finer sand grades and clayey sands within the named soil classes may also be suitable. The most desirable range of hydraulic conductivity is 10^{-4} to 10^{-5} cm/sec. In their natural condition, the forenamed classes could be too permeable for wetland vegetation to establish itself. For example, design for four inches per week application would call for hydraulic conductivity of around $10^{-4.8}$ cm/sec, which is close to the lower limit of infiltration indicated for the first three classes named. However, the permeability of many soils can be reduced during construction due to compaction. Because compaction may decrease the soil's water hydraulic conductivity by an order of magnitude or more, care in achieving the right degree of compaction is important. The GM, SM, and SC soils may be readily compactible (fair to good workability). The OL and MH materials are usually difficult to work and to compact, and the OL soils may support only light equipment.

Natural Marshes--

In some cases, natural marshes may be used for treatment of domestic wastewater with very few modifications. A levee to enclose the area may be desirable, as might levees which divide the area into sections. However, such subdivision has not been incorporated in any existing full scale systems considered in this study. As with other natural treatment systems, it is generally advisable to carry out pilot studies prior to committing a large wetland area to be used in wastewater treatment. Establishment and monitoirng of appropriate control areas is also generally advisable.

TABLE 28. UNIFIED SOIL CLASSES AND HYDRAULIC CONDUCTIVITIES (Reference 37)

ASTM Soil Class	Typical Names	Workability
Hydraulic Conductivity 10^{-3} to 10^{-6} cm/sec		
GM	Silty gravels & Gravel - sand - silt	Good
SM	Silty sands & Sand silt mixtures	Fair
SC	Inorganic silts Very fine sands Silty or clayey find sands Clayey silts (low plasticity)	Fair
Hydraulic Conductivity 10^{-4} to 10^{-6} cm/sec		
OL	Organic silts Organic silty clays (Low plasticity)	Poor
MH	Inorganic silts Micaceous or diatomaceous Fine sandy or silty soils Elastic silts	Poor

Artificial Wetland --

Preliminary design criteria for some types of artificial wetland have been developed by Tchobanoglous and Culp (Reference 31) who used data found in the literature. It is presented in Table 29. The criteria presented are for the application of primary or secondary effluent.

Cypress Domes, Strands or Swamps--

Cypress domes, strands, and swamps are different types of southern wetlands dominated by cypress trees. The application rate to cypress domes is generally 1.9 to 2.5 cm per week, to allow for percolation. Often more than one dome will be needed to accommodate the total wastewater flow. A cypress strand is a flow-through system. These systems require a holding pond having 3-14 day storage capacity to 1) attenuate

TABLE 29. PRELIMINARY DESIGN PARAMETERS FOR PLANNING ARTIFICIAL WETLAND WASTEWATER TREATMENT SYSTEMS[a] (Reference 31)

		Characteristic/design parameter					
Type of system	Flow regime[b]	Detention time, days		Depth of flow, m (ft)		Loading rate ha/1000 m^3/day (acre/mgd)	
		Range	Typical	Range	Typical	Range	Typical
Trench (with reeds or rushes)	PF	6-15	10	0.3-0.5 (1.0-1.5)	0.4 (1.3)	1.2-3.1 (11-29)	2.5 (23)
Marsh (reeds rushes, others)	AF	8-20	10	0.15-0.6 (0.5-2.0)	0.25 (0.75)	1.2-12 (11-112)	4.1 (38)
Marsh-pond							
1. Marsh	AF	4-12	6	0.15-0.6 (0.5-2.0)	0.25 (0.75)	0.65-8.2 (6.1-76.7)	2.5 (23)
2. Pond	AF	6-12	8	0.5-1.0 (1.5-3.0)	0.6 (2.0)	1.2-2.7 (11-25)	1.4 (13)
Lined trench	PF	4-20	6			0.16-0.49 (1.5-4.6)	0.20 (1.9)

[a] Based on the application of primary or secondary effluent.
[b] PF = plug flow, AF = arbitrary flow.

peak loading; 2) settle gross suspended solids; and 3) provide temporary storage for wetland maintenance. The water level should be kept below the cypress tree knees. Permanent flooding above the knees will kill the trees. It is important during construction not to disturb the mucky organic sediments in a cypress dome. This layer controls the slow percolation to the ground water, thus avoiding its contamination. Cypress domes have received wastewater through a stand pipe while gated, aluminum irrigation header pipe with inlets every 15 to 30 m have generally been used in cypress strands. The dome's perimeter should be diked and perhaps fenced with a buffer zone between the dome and swamp animal population.

Bogs and Peatlands--

Bogs and peatlands are sensitive ecosystems. It is important that the method of introduction of the wastewater does not disturb the vegetative mat. The distribution line may be attached to a raised walkway which is anchored in the clay beneath the peatland. Distribution lines constructed of gated aluminum irrigation header pipe or PVC have been used successfully.

ENERGY ANALYSIS

One of the advantages of wetland systems is their lower operational energy requirements compared with conventional treatment plants. If the topography of the site allows gravity flow from the treatment plant to the wetlands then there will not be any operational energy demands except for those of the maintenance vehicles. However, if gravity flow to the wetlands is not feasible, pumping will be required, resulting in additional energy demands. If the pumping demands are large, energy requirements could approach those of a conventional treatment plant.

The energy required by pumping is a function of wastewater flow rate, the length of pipeline (the distance from the treatment plant to the wetlands), the hours of operation, the diameter of the pipe, and any static lift and dynamic head losses.

All these variables could be combined in many different combinations, and one combination cannot be singled out as a "typical" example to evaluate. Instead, Figure 5 has been prepared to enable the pumping energy requirements to be estimated for a specific site. Each graph contains a family of curves representing individual average daily flows. These four graphs give the horsepower required to overcome friction losses for different diameter pipes and distances between the treatment plant and the wetlands. The calculated power required is only for the friction losses in the pipe and does not include any static lift.

Pumping may also be required to overcome any static lift between the pretreatment effluent discharge and the wetlands system inlet and to increase the head to insure quantity flow through the wetland system. Figure 6 has been prepared to give the horsepower required for different flow rates and static lifts. This horsepower can be directly added to the friction-loss horsepower to obtain the total horsepower required.

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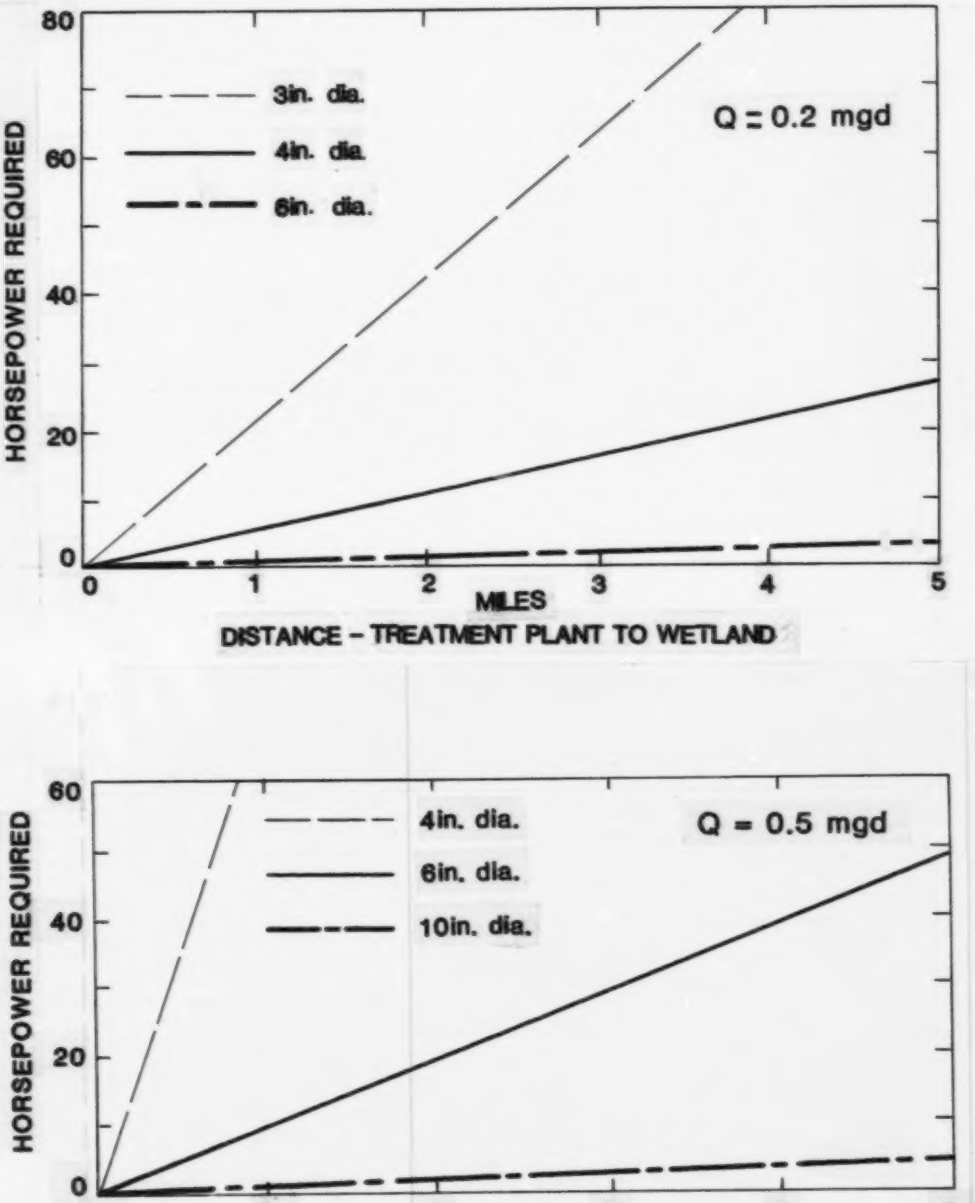

Figure 5. Power required to overcome friction loss, for various flow rates (continued).

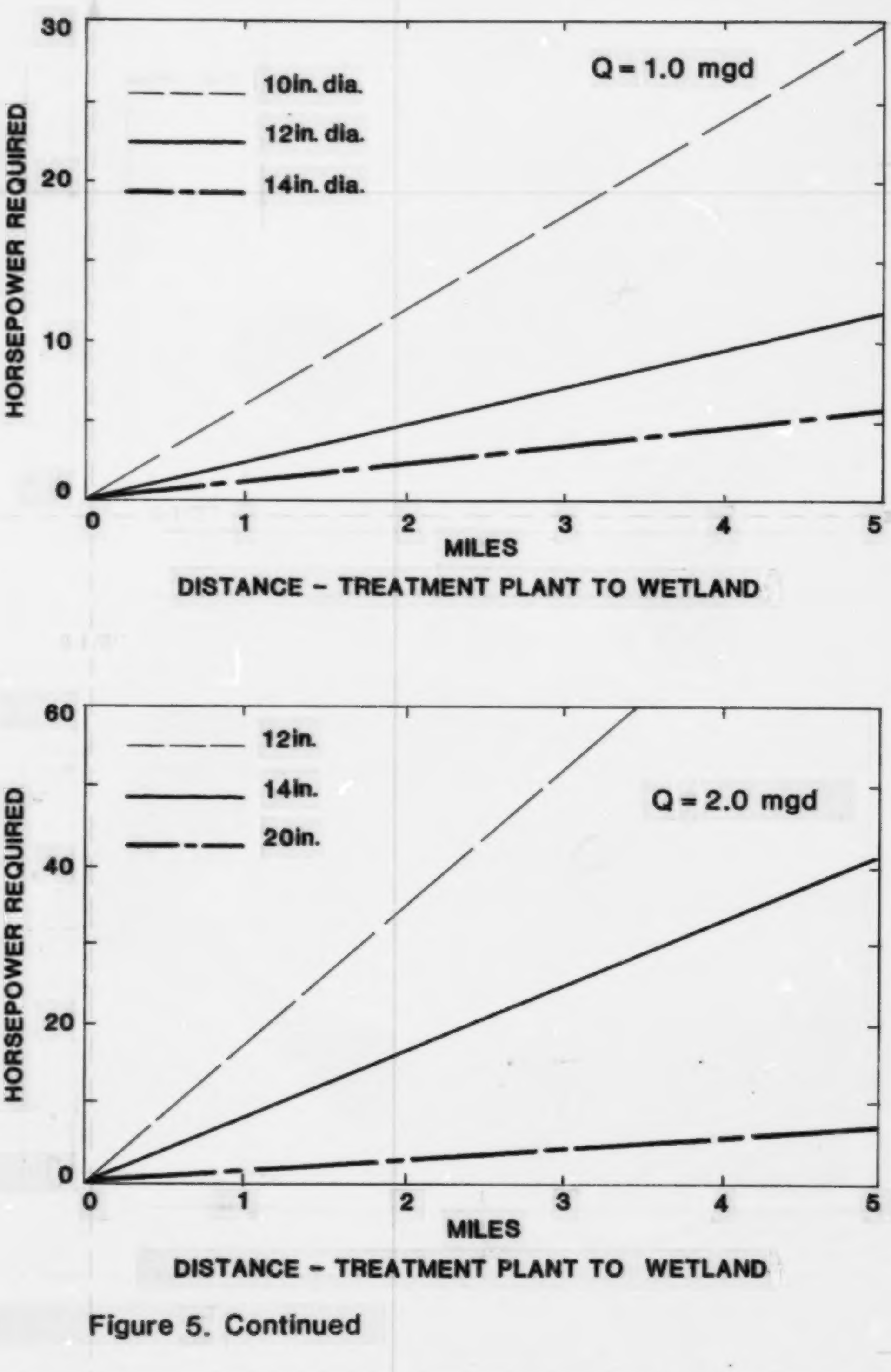

Figure 5. Continued

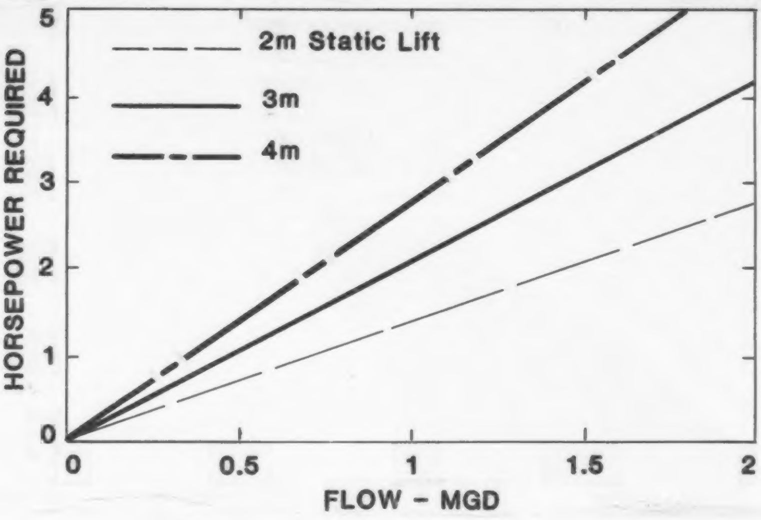

FIGURE 6. Static lift - power requirements.

The annual energy required (in kWh) can be calculated, by multiplying the horsepower required, as determined from the graphs, by the hours of operation expected per year, then converting to kWh (1 hp = 0.747 kWh). An example problem using Figures 5 and 6 follows:

Given: Flow = 3790 cu m/day (1 mgd).
Distance between treatment plant and wetlands = 3.2 Km (2 miles), 14 inch diameter pipe.
Difference in elevation between treatment discharge and wetlands inlet = 2.13 m (7 ft).
Head required for gravity flow = 0.87 m (2 ft).
Pumps in operation 16 hours/day, 365 days/year.

Find: Energy required for pumping.

Solution: First find the horsepower required to overcome the friction losses by using Figure 5. At 2 miles and for a 14 inch pipe, the horsepower required is about 2.5 hp.

Next determine the power required to overcome the static lift. The static lift would be the difference in elevation (2.13 m) plus the head required (0.87 m) or 3 m. From Figure 6, the horsepower required is 2.1 hp.

The total horsepower is 2.5 hp plus 2.1 hp or 4.6 hp.

The annual hours of operation are:

$$\frac{16\ \text{hr}}{\text{day}} \times \frac{365\ \text{days}}{\text{year}} = \frac{5840\ \text{hrs}}{\text{year}}$$

The total annual energy required is:

$$\frac{5840\ \text{hrs}}{\text{year}} \times 4.6\ \text{hp} \times \frac{0.7457\text{kW}}{\text{hp}} = \frac{20{,}000\ \text{kWh}}{\text{year}}$$

It has been estimated that a 3,785 cu m per day (1 mgd) plant would require about 5700 liters (1,500 gal) a year of gasoline for operating a maintenance vehicle. This volume of gasoline has an equivalent energy value of 1.58×10^8 MJ (44,000kWh) (Reference 30).

Energy consumption during construction also varies widely. A natural wetlands may or may not require major constructed modifications. The energy consumed during the construction of a wetland is a function of the method of construction and the volume of earth moved. The amount of energy used can be estimated from the energy construction costs and knowing the unit cost of energy at the time of construction. The cost of energy used is about 5 percent of the total construction cost.

OPERATION AND MAINTENANCE REQUIREMENTS OF WETLAND TREATMENT SYSTEMS

Wetland treatment systems have low operation and maintenance (O&M) requirements. Information is available for some of the full scale projects. Tables 30 and 31 summarize labor and O&M requirements.

Helle (personal communication) relates that there is no daily maintenance requirements for cypress dome systems. However, the distribution system may require daily checks if pumps are involved. Every several years vegetation may need to be planted or harvested and the subtrate examined.

Williams and Sutherland report that daily maintenance on the Vermontville, MI seepage wetlands is restricted to seasonal flow control. The other major maintenance activity is mowing vegetation on the berms. There has been no substrate or vegetation maintenance activities necessary during the first six years of operation. Three to four inches of organic debris has accumulated in six years.

TABLE 30. LABOR FOR MAINTENANCE OF WETLAND TREATMENT SYSTEMS

System	Type*	Years in Service	Area ha	Annual Flow m^3/year	Operator hours/ Year	Operator hours/ ha/year	Operator hours/ cu m/yr
Bellaire, MI	N	4	15	$1.1x10^6$	200	13	$1.8x10^{-4}$
Meadow/Marsh/ Pond Estimate**	A	—	—	$9.5X10^5$	3120	—	$3.3x10^{-3}$
Vermontville, MI	A	6	4.65	$9.5x10^4$	400	86	$4.2x10^{-3}$
Mt. View Sanitary Dist., CA	A	6	8.1	$1.1x10^6$	1300	160	$1.2x10^{-3}$

* N = natural, A = Artificial

**Based on pilot work at Brookhaven by Small.

TABLE 31. SUMMARY OF TYPICAL MAINTENANCE TASKS

Daily	Periodic
Water Quality Monitoring	Erosion Control
Flow Records and Meter Upkeep	Levee Repair
Visual Inspection of Flow Structures: Weirs, Flumes, Pipes, etc.	Vegetation Harvest
	Pumps Maintenance
	Distribution Lines
	Vehicles

Kadlec and Tilton give a detailed description of O&M activities for the Bellaire, MI natural wetlands system. Flow meters and water distribution and discharge structures need to be checked daily. Levee maintenance and repair is crucial. During winter and spring it occasionally becomes necessary to chemically increase the level of dissolved oxygen in the Bellaire system. Sodium nitrate is added to the water to accomplish this. This is the only chemical addition to a wetland system mentioned in any of the literature reviewed for this report.

Demgen describes the artificial wetlands at Mt. View Sanitary District, CA which has been in operation six years. The primary O&M activities are water quality monitoring, levee repair and vegetation control. The monitoring effort is variable. Levee repairs can be minimized through proper design. Vegetation control depends on management goals. Vehicle and flow structure repairs are periodic.

In a multi-cellular wetland treatment system, one of the best management tools available is the ability to take a cell out of service. This flexibility of flow paths allows the wetlands manager to respond quickly to possible vector or disease situations and also allows the performance of major maintenance tasks. A cell could be flooded to permit fish predation on mosquito larvae or drawn down to enable access to a portion of a failing levee. The complete desiccation of a cell would facilitate major repairs, design renovations or vegetation control measures.

One of the major questions regarding wetland O&M is vegetation control and harvesting. Of the thirteen full scale projects investigated, none reported major vegetation harvesting. In one artifical marsh project, vegetation control measures have been taken, including deepening some channels to prevent colonization. Floating harvesters were also tried on the same project with little success, and only the tops of the plants, not the roots, were removed, so regrowth was a possibility. A major reason for harvesting vegetation is to resolve a problem. Examples of possible vegetation induced problems are: poor circulation yielding inefficient treatment, mosquito breeding, and odors due to stagnation.

It is possible for wastewater wetlands, as with most natural wetlands, to emit odors. Some of the projects reported that slight odors were created. Avoiding odors is accomplished by maintaining aerobic conditions through circulation of water within the system.

Vector production can be minimized through proper management. Certain species of mosquitos may carry pathogens. The wetland's proximity to housing will determine the degree of concern. A very successful management tool in controlling mosquito larvae has been the introduction of Gambusia spp., mosquito fish. Adequate circulation is important to minimize stagnant conditions.

Operations and maintenance tasks can be minimized through proper design. O&M tasks can generally be accomplished by a well trained operator. Often the time required is sporadic; for example, two persons may be required for three full days for levee repair. However, such a task may not be required again for many months. It is critical that a biologist familiar with wetland habitats be available for consultation on each project. This is due to the fact that both natural and artificial wetlands are complex ecosystems.

COSTS

The costs of a wetland system can be divided into two categories; construction (capital) and operation. Possible costs incurred for construction include land acquisition, earth work, artificial lining, pumps and piping and miscellaneous equipment. The major operational costs include labor, maintenance of equipment, energy if pumps are required, and monitoring. As previously emphasized, each system is unique and therefore the cost will be variable.

Construction Cost

The largest construction expense for an artifical wetlands is the earthwork. Earthwork consisting of excavation, backfilling and dike construction at approximately $6.50 per cu m ($5/cu yd) was used for this report. Figures 7 and 8 give the estimated cost for various earthwork volumes. Figure 7 is for small scale projects, 10,000 cu m or less and Figure 8 is for large projects, up to $4x10^6$ cu m.

The purchase price of the land can also be a major expense in developing a wetland system. Since wetlands are land intensive, it is important that the available land is reasonably priced to keep the system cost-effective. Land cost vary across the nation, ranging from $2470 to $4942 per ha ($1000-2000 per acre) or higher. A reliable estimate for a specific site should be used when estimating land costs.

If a wetland system requires wastewater pumping, those facilities must be included in the cost analysis. The construction cost of a pump station has been estimated and is presented on Figure 9 as a function of the pumping capacity (based on Reference 6). These costs include the pumps, the structural housing and foundation. The pump station piping and various appurtenances increase the cost an additional 30 percent over the values shown in Figure 9. This 30 percent should be included in the total capital cost.

For systems which are not designed for seepage into the soil, impermeable clay or artificial membrane liners may need to be installed. Presently only the trench systems utilize them. The costs of various membrane liners are found in Table 32.

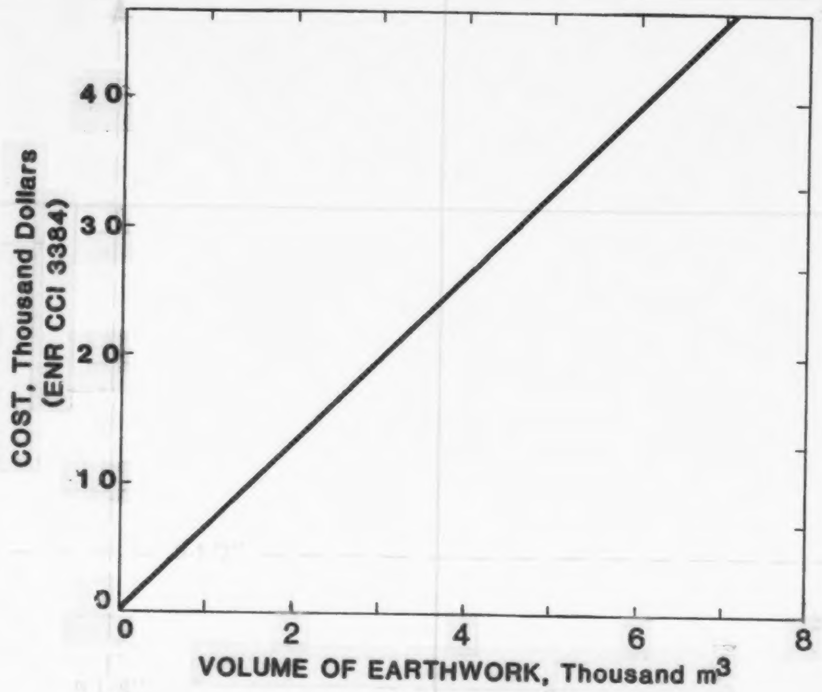

Figure 7. Cost of earthwork for small projects.

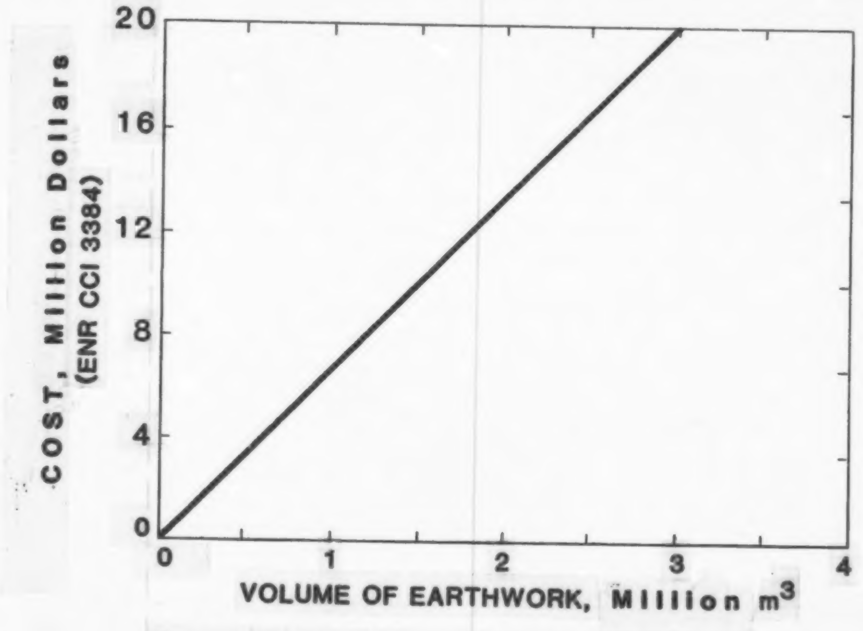

Figure 8. Cost of earthwork for large projects.

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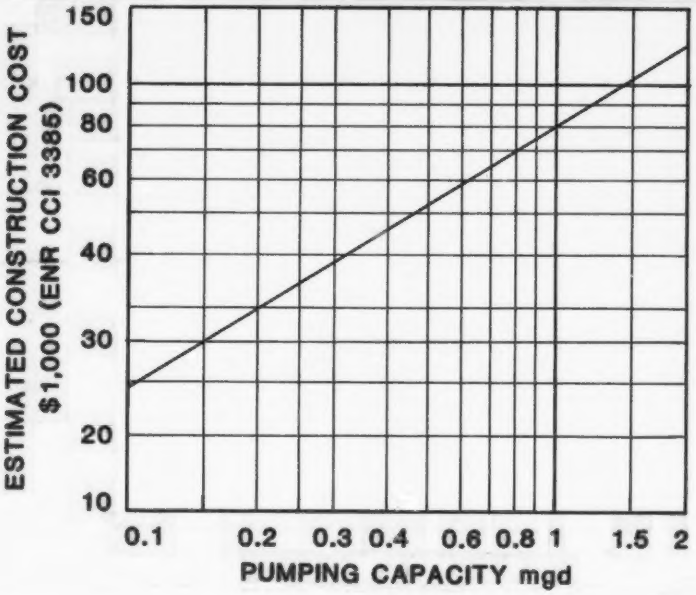

Figure 9. Estimated construction cost of pump station.

Miscellaneous capital costs are common to all construction projects. Costs specific to wetlands may include, but do not necessarily require the following: the distribution system, vegetation seeding, roads, sitework, fencing, lighting, instrumentation, and monitoring equipment. There are also the professional fees for engineering design, biology consultants, legal and administrative services. The individual cost of each is relatively small compared to the total construction cost, but combined they become a significant cost. The collective miscellaneous costs are usually estimated to be an additional 25-35 percent of the the construction cost. For a conservative estimate the 35 percent value is used in this report.

Operation and Maintenance Costs

The previous section discussed the normal tasks involved in operating and maintaining a wetlands treatment system. If the system is designed properly, one of the largest operating expense is labor. Labor estimates are based on the periodic and routine tasks that are in the O&M schedule, and on the surface area of land to be maintained. The operations requirements from actual experience listed in Table 30 do not correlate with the volume of flow or the wetland's surface area. Therefore, they are not used to make general estimates.

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TABLE 32. COST OF ARTIFICIAL MEMBRANE LINERS

Material and Fabricator	Thickness (mil)	Expected life (yrs)	Warranty (yrs)	Cost[a] \$/m^2 (\$/ft^2)
HYPALON-R				
Globe-3 ply	30	20	20	23 (0.65)
Globe-5 ply	45	20	20	28 (0.80)
Watersaver	36	20	20	23 (0.65)
Staff	45	20	20	23 (0.65)
CPE-R				
Watersaver	36	10-20	none	21 (0.60)
PALCO	36	10-20	none	16 (0.45)
Staff	--	--	none	21 (0.60)
PVC - Watersaver	--	5	none	--
PVC-R - PALCO	20	3-5	none	12 (0.35)
NEOPRENE - Watersaver	21	--	none	37 (1.05)
URETHANE - Cooley, Inc.	--	?	none	--
PVC COMPOSITE - Globe & Putterman	--	10	10	59 (1.68)

[a] ENR CCI 3384

Another operating expense which has the potential of being the major expense, is the environmental monitoring. Actual costs will vary depending on the level of monitoring required by the NPDES permit. At the Vermontville Wetland, Michigan, the environmental monitoring costs were 43 percent of the 1980-81 Annual O&M Budget, and at Houghton Lake, Michigan, they were 53 percent in 1980 (Jeff Sutherland, personal communication). Typical monitoring programs range between 20 and 50 percent of the operating budget.

The O&M schedule is the most influencing factor in evaluating the labor cost. For a specific wetlands, the annual labor cost can be easily estimated once the O&M schedule has been developed and the hourly rate of labor is known.

When pumping is required, energy can be a costly item. Specific costs can be estimated from the annual energy requirements (in kWh) developed in the previous energy analysis and by knowing the current electricity rate.

If an agency does not have a biologist on staff, a consultant may be retained. Routine consultation will amount to about 100 hours a year.

Miscellaneous costs include periodic repairs of levees, maintenance of vehicles and equipment, energy, and general site maintenance. As with the construction cost, the miscellaneous costs can be estimated as a percent of the annual O&M budget. A range of reasonable percentages should be based on actual data. At this time operation of the existing wetland systems is quite varied and reliable estimates can not be extrapolated. However, an operator or engineer with experience will be able to make reasonable estimates for a specific wetland system once the O&M schedule is defined.

SECTION 5

COMPARISON WITH EQUIVALENT CONVENTIONAL TECHNOLOGY

INTRODUCTION

In Section 4, it was concluded that selecting an example of a "typical" wetland system would be too subjective and could be misleading because of the many different wetland types, site specific variables, and the lack of established design criteria. However, in order to compare the wetlands systems with conventional wastewater treatment technology, a range of annual costs and energy demands for wetland systems was developed. The values generated are conservative and for comparison purposes only.

To keep the comparison simple and representative, only one type of wetlands was evaluated. An artificial wetland was chosen rather than a natural one for two reasons. First, using an artificial system will produce more conservative values since more capital expenses are associated with the construction of an artificial wetland. Second, estimating the construction required to convert a natural wetland into a wastewater treatment wetland is difficult since this is based on site specific conditions. Of the four prominent types of artificial wetlands (Table 1), artificial marsh systems have been selected because 1) they appear to have a large range of application; 2) the four existing full scale artificial wetlands are or include marsh systems; and 3) there is more available data on marsh systems than other wetland types.

The cost and energy requirements for a wetlands system vary for different levels of treatment. Cost and energy analyses were developed for three treatment levels; secondary, advanced secondary and AWT. These three cases are defined below. The removal rates are based on actual full scale results discussed in Section 3 and shown in Table 26. The surface loading rates are from Table 29 which are based on the full scale operations. The depth for all cases is 15 cm (0.5 ft).

Treatment Quality

Case 1: Secondary Treatment

	BOD_5	TSS	N	P
Influent (mg/l)	150	100	40	8
Effluent (mg/l)	30	30	29	6.4
Percent removed	80	70	30	20

Surface loading rate = 4 ha/1000 cu m/day, 37 acre/mgd
Volume of excavation required = 6000 cu m/1000 cu m/day

Case 2: Advanced Secondary Treatment

	BOD_5	TSS	N	P
Influent (mg/l)	30	30	28	6.4
Effluent (mg/l)	15	15	11	2.6
Percent removed	50	50	60	60

Surface loading rate = 3.0 ha/1000 cu m/day, 28 acre/mgd
Volume of excavation required = 4500 cu m/1000 cu m/day

Case 3: AWT

	BOD_5	TSS	N	P
Influent (mg/l)	15	15	11	2.6
Effluent (mg/l)	8	8	4.3	1.1
Percent removed	50	50	60	60

Surface loading rate = 2.5 ha/1000 cu m/day, 23.3 acre/mgd
Volume of excavation required = 3750 cu m/1000 cu m/day

Based on the above values, the total surface area requirements were computed and are shown in Table 33.

TABLE 33. SURFACE AREA REQUIRED FOR MARSH WETLAND SYSTEM (IN HECTARES)

Flow (cu m/day)	Case 1	Case 2	Case 3
400	1.6	1.2	1.0
800	3.2	2.4	2.0
2000	8.0	6.0	5.0
4000	16	12	10
8000	32	24	20

COST ANALYSIS

Cost estimating procedures used in this report follow the US EPA's cost-effectiveness guidelines. Cost-effectiveness is defined to include monetary cost and environmental and social impact assessment. Capital cost estimates are based on the Engineering News Record Construction Cost Index (ENR CCI) 20 cities average, March 1981. Capital costs are based on an operable system with a 20-year life. If a system has an expected service life of less than 20 years, the O&M cost includes the annual present worth of subsequent replacement required to obtain a 20-year service life. Salvage value for estimated service life beyond 20 years is considered for land and equipment as allowed by the EPA guidelines.

Capital costs include construction, engineering, legal, administration and contigencies for all building, equipment and appurtenances. Annual operation and maintenance costs include labor, energy, chemicals and routine replacement of parts and equipment (when replacement is required at intervals of five years or less). Equipment cost estimates were based on preliminary layouts and sizing, appropriate redundance, quotations from equipment manufacturers and recent contract bids as available. Operating cost escalations are projected to be approximately 10 percent per year. The assumptions made for the energy estimates in the previous energy section apply.

Basic cost assumptions include:

Service life = 20 years

Life cycle cost interest rate (EPA required) = 7 percent

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Non-component costs = Piping @ 10%
Electrical @ 8%
Instrumentation @ 5%
Site preparation @ 5%
Total = 28% of construction cost

Non-construction costs = Engineering and construction supervision @ 15%
Contingencies @ 15%
Total = 30% of construction and non-construction costs

Capital cost = Construction cost plus non-component and non-construction costs

Capital recovery factor = 20 years, 0.09439

Present worth factor = 10.594 times annual operating cost

ENR CCI (20 cities average March, 1981) = 3384

Labor cost, rural community (March, 1981) = $11/hour

Energy cost (March, 1981)
- Electricity (industrial rate) = $0.11 MJ ($0.04/kilowatt hour)
- Gasoline = $0.396/liter ($1.50/gallon)

Energy cost escalation factor
- Electricity
  - 1980-1990 = 28%
  - 1990-2000 = 6%
- Gasoline
  - 1980-1990 = 34%
  - 1990-2000 = 21%

As discussed in Section 4, capital costs include earthwork, land acquisition, artificial lining, pumps and piping, and miscellaneous equipment and costs. The operational costs include labor, maintenance of equipment, energy if pumps are required and miscellaneous costs.

The major construction cost is earthwork which includes excavation, grading, berm construction and compaction. The estimated cost is $6.50/cu m ($5/cu yd). Table 34 shows the estimated cost of earthwork, for various flows, for the three cases.

TABLE 34. COST ESTIMATE OF EARTHWORK FOR MARSH WETLAND SYSTEMS, IN THOUSANDS OF DOLLARS (ENR CCI 3384)

Flow (cu m/day)	Case 1	Case 2	Case 3
400	15.7	11.7	9.7
800	31.3	23.3	19.7
2000	78.7	58.7	49.0
4000	157.0	117.0	9.7
8000	313.0	233.0	19.7

The cost of land varies across the country. A suggested range is $2,470-4,942 per hectare ($1,000-2,000 per acre) (Reference 34). For this cost comparison, the value of $3,000 per hectare ($1,335 per acre) is used. Table 35 summarizes the land acquisition cost for the three cases at various flows. A cost sensitivity analysis indicates that land acquisition costs may vary between 1 to 10 percent of the total present worth cost of the system.

In many cases, suitable wetland sites are already owned by the municipality or by State and Federal agencies. These site acquisition costs may not be significant for many projects.

TABLE 35. COST OF LAND ACQUISITION FOR MARSH WETLAND SYSTEMS, IN THOUSANDS OF DOLLARS (ENR CCI 3384)

Flow (cu m/day)	Case 1	Case 2	Case 3
400	4.9	3.7	3.0
800	9.6	7.1	6.1
2000	24.0	18.1	15.0
4000	49.0	37.0	30.0
8000	96.0	71.0	60.0

From the design data of full scale wetlands (Table 21), it is observed that only 3 of the 15 facilities require pumping to the system and none of them require pumping within the system. Since pumping is not common in full scale application, pumps and costs associated with pumping will not be considered in this cost comparison.

All of the 15 full scale facilities use soil as a substrate lining. Artificial liners appear not to be the common practice and, therefore, will not be included in this cost estimate.

A wetland system will usually require the use of a utility vehicle. It is assumed that the municipality will already own a vehicle for this purpose. Therefore, the capital cost of the truck will not be included. An appropriate portion of the vehicle's maintenance and replacement cost will be included in the wetland O&M budget.

The total capital cost including non-component and non-construction costs for each case at the various flows is summarized in Table 36.

TABLE 36. TOTAL CAPITAL COST FOR AN ARTIFICIAL MARSH WETLAND SYSTEM, $ THOUSANDS (ENR CCI 3384)

Flow (cu m/day)	Case 1	Case 2	Case 3
400	34.3	25.63	21.1
800	68.1	50.59	42.9
2000	170.86	127.8	106.5
4000	342.8	256.1	211.4
8000	680.6	505.9	429.0

One of the largest O&M cost elements is the labor required for the routine operation of the system. The actual labor requirements experienced in full scale systems was presented in Table 30 and they ranged from 86 to 160 operator hours/ha/year for artificial wetlands systems. The rate of 160 o.h./ha/yr will be used here for a conservative estimate. Table 37 shows the expected labor requirements for the three cases at various flows.

The utility vehicle O&M cost includes gasoline, routine maintenance, and replacement cost. Reference 26 suggests 1500 liters of gasoline/1000 cu m/day per year (1500 gal/mgd/year).

TABLE 37. ANNUAL LABOR REQUIREMENTS FOR OPERATION AND MAINTENANCE OF AN ARTIFICIAL MARSH WETLAND SYSTEM, OPERATOR HOURS PER YEAR

Flow (cu m/day)	Case 1	Case 2	Case 3
400	256	192	160
800	512	384	320
2000	1280	960	800
4000	2560	1920	1600
8000	5120	3840	3200

TABLE 38. ANNUAL O&M COSTS OF WETLAND UTILITY VEHICLE (ENR CCI 3384)

Flow (cu m/day)	Cost
400	$ 2,240
800	$ 3,200
2000	$ 5,000
4000	$ 8,000
8000	$14,000

The utility vehicle can be assumed to have an annual maintenance cost of $1,000 and a replacement cost of $1,000/year. The annual O&M cost of the vehicle is summarized in Table 38, assuming a gasoline cost of $0.40/liter ($1.50/gal).

Since pumping is not included in this system, there will not be any associated electrical cost. Miscellaneous cost, including utilities, piping repair, and consultant biologist, was estimated to be 15 percent of the annual O&M cost. As mentioned previously, environmental monitoring can be a significant expense. For this cost analysis it was assumed that environmental monitoring would be 30 percent of annual O&M cost (including the above mentioned miscellaneous costs). Table 39 summarizes the total annual O&M costs.

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TABLE 39. ANNUAL O&M COST FOR A MARSH WETLAND SYSTEM (ENR CCI 3384)

Flow (cu m/day)	Case 1	Case 2	Case 3
400	$ 7,500	$ 6,440	$ 5,910
800	$12,000	$ 9,870	$ 8,830
2000	$41,100	$36,600	$20,000
4000	$48,100	$37,500	$32,200
8000	$91,400	$71,700	$61,300

There are 15 situations (3 different cases and 5 different flow rates) which could be analyzed. To keep this assessment concise, only one flow rate will be used for the 3 cases studied for the detailed cost analysis. The methodology used for the cost estimate can be applied for any of the flow rates and combination of cases. A flow rate of 4000 cu m/day (1.06 mgd) has been chosen as the representative flow for small communities. Other assumptions include:

- System is operating 12 months a year.
- Pumping is not required.
- Artificial liner is not required.
- Land costs are $3,000 per ha ($1,335 an acre).
- The salvage value of land is calculated by escalating the purchase price by 1.806 (appreciation at a compound interest rate of 3%/year for 20 years). The present worth of the salvage value at the end of 20 years is that value multiplied by the single payment present worth factor @ 7% for 20 years (0.2584).

The average annual cost for Case 1, primary effluent to secondary, is $78,240, for Case 2, secondary effluent to advanced secondary, is $59,980, and for Case 3, advanced secondary effluent to AWT, is $50,280. The cost breakdowns are presented for each case in Tables 40, 41 and 42.

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TABLE 40. ESTIMATED COSTS FOR A MARSH WETLAND SYSTEM, CASE 1, 4000 cu m/day, ENR CCI 3384

Item	Capital	Annual O&M	Present Worth O&M	Total Present Worth	Average Annual
Earthwork	$157,000				
Land Acquisition	49,000				
Labor	—	$28,200			
Utility Vehicle	—	2,000			
Subtotal 1	206,000	30,200			
Non-component costs @ 28%	57,700	—			
Misc. O&M @ 15%	—	4,500			
Subtotal 2	263,700	34,700			
Environmental monitoring		10,400			
Non-construction costs @ 30%	79,100				
Subtotal 3	342,800	45,100	$478,000	$821,000	$77,500
Energy: gasoline		2,400	30,700	30,700	2,900
Subtotal 4				851,700	80,400
Land Salvage value (subtract)				22,900	2,160
TOTAL				$828,800	$78,240

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TABLE 41. ESTIMATED COSTS FOR A MARSH WETLAND SYSTEM, CASE 2, 4000 cu m/day, ENR CCI 3384

Item	Capital	Annual O&M	Present Worth O&M	Total Present Worth	Average Annual
Earthwork	$117,000				
Land Acquisition	37,000				
Labor	—	$21,100			
Utility Vehicle	—	2,000			
Subtotal 1	154,000	23,100			
Non-component costs @ 28%	43,000	—			
Misc. O&M @ 15%	—	3,500			
Subtotal 2	197,000	26,600			
Environmental monitoring		7,980			
Non-construction costs @ 30%	59,100				
Subtotal 3	256,100	34,580	$366,000	$622,100	$58,700
Energy: gasoline		2,400	30,600	30,600	2,900
Subtotal 4				652,700	61,600
Land Salvage value (subtract)				17,300	1,630
TOTAL				$635,400	$59,980

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TABLE 42. ESTIMATED COSTS FOR A MARSH WETLAND SYSTEM, CASE 3, 4000 cu m/day, ENR CCI 3384

Item	Capital	Annual O&M	Present Worth O&M	Total Present Worth	Average Annual
Earthwork	$ 97,000				
Land acquisition	30,000				
Labor	—	$ 17,600			
Utility Vehicle	—	2,000			
Subtotal 1	127,000	19,600			
Non-component costs @ 28%	35,600	—			
Misc. O&M @ 15%	—	2,940			
Subtotal 2	162,600	22,540			
Environmental Monitoring		6,750			
Non-construction costs @ 30%	48,800				
Subtotal 3	211,400	29,290	$310,000	$521,000	$ 49,200
Energy: gasoline		2,400	30,600	30,600	2,400
Subtotal 4				551,600	51,600
Land Salvage value (subtract)				14,000	1,320
TOTAL				$537,600	$ 50,280

Cost Comparison

A range of average annual costs for conventional secondary and advanced treatment systems were developed by completing a present worth analysis of the cost data from the EPA Innovative and Alternative Technology Assessment Manual (Reference 32). These costs are the unit costs for various secondary and advanced secondary treatment systems. The cost of treating the influent (i.e. primary effluent or secondary effluent) is not included. The cost of the following conventional secondary treatment systems were included in the development of the cost curves: activated sludge (mechanical aeration, high rate diffused aeration, pure oxygen), trickling filters, rotating biological contactors, and contact stabilization. The costs for conventional systems include solid separation (i.e. clarification) and sludge handling (i.e. dewatering, digestion, disposal). The costs for the wetland systems do not include sludge processing and disposal since it was assumed that sludge would not be removed from the systems. The cost of the following processes were used for conventional advanced secondary and AWT costs curves: dual media filters, activated carbon, Phostrip, ion-exchange, break point chlorination and ammonia stripping.

The range of costs are presented in two graphs, Figure 10 for secondary treatment and Figure 11 for advanced secondary and AWT. These figures show the annual average cost as a function of plant capacity for both the conventional and wetland systems. The ranges given for each system are based on the cost estimate previously detailed.

Estimated savings, based in Figures 10 and 11, for secondary and advanced waste treatment are shown in Table 43. Since the annual costs for the conventional systems are presented over a range, the mid-point cost for a given flow rate was used for the comparison.

TABLE 43. COMPARISON BETWEEN WETLAND AND CONVENTIONAL SYSTEMS ANNUAL AVERAGE COSTS (ENR CCI 3384)

Treatment Type	Flow rates			
(cu m/day)	400	2000	4000	8000
(mgd)	0.11	0.53	1.06	2.11
Secondary				
Conventional	$28,000	$ 70,500	$111,000	$175,000
Wetlands (Case 1)	10,500	44,000	78,300	153,000
Savings	17,500	26,500	32,700	22,000
	63%	38%	29%	13%
Advanced Secondary & AWT				
Conventional	40,000	122,000	202,500	325,000
Wetlands (Case 2)	8,700	29,000	60,100	116,000
Savings	31,300	93,000	142,400	209,000
	78%	76%	70%	64%

The calculated savings shown in Table 43 indicate that the highest savings are realized at the lower flow rates and that advanced wetland treatment provides more savings than secondary wetland treatment systems.

The average annual cost can be divided into two components: capital and annual O&M costs. Graphs for each of these components were developed from Reference 32. Figure 12 shows the capital cost as a function of plant capacity for

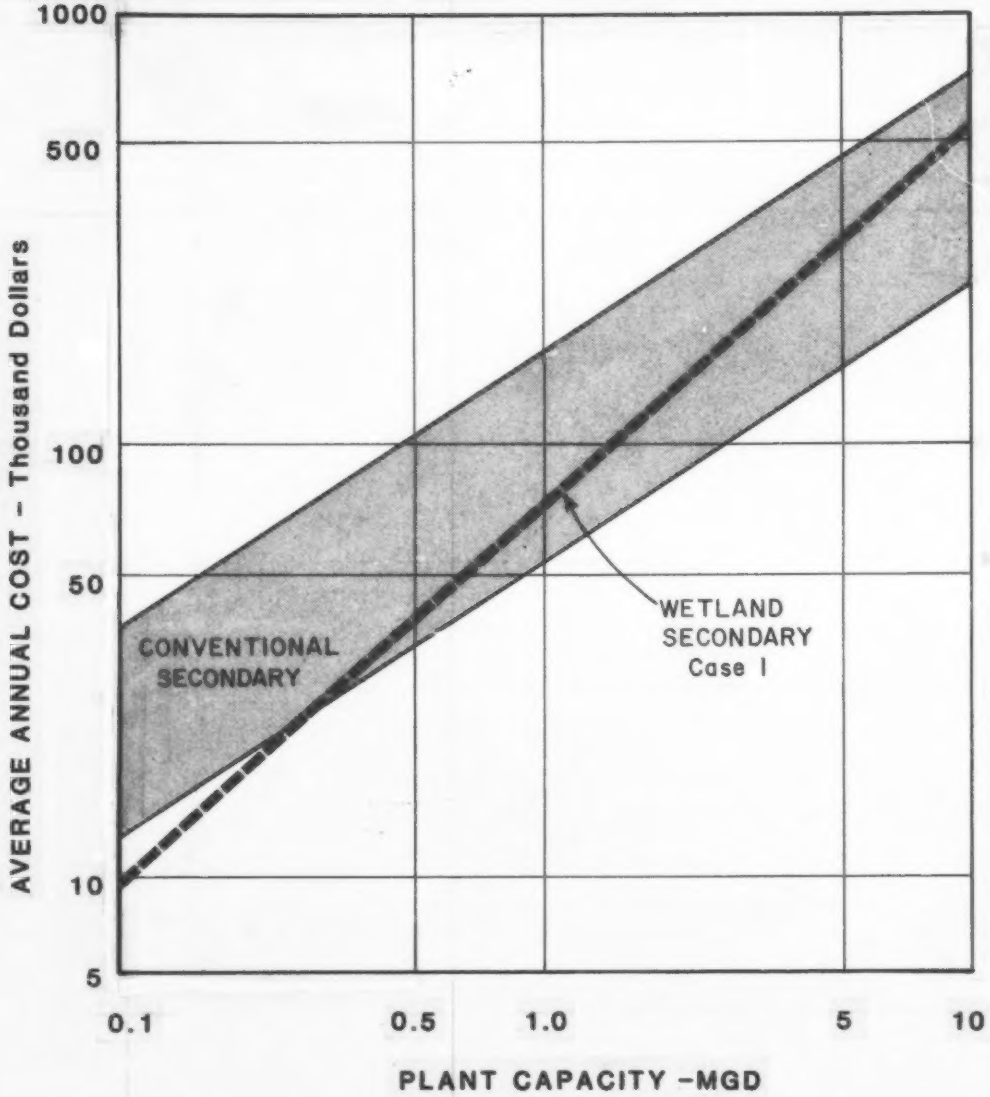

FIGURE 10. Average Annual Costs Comparison - Secondary Treatment.

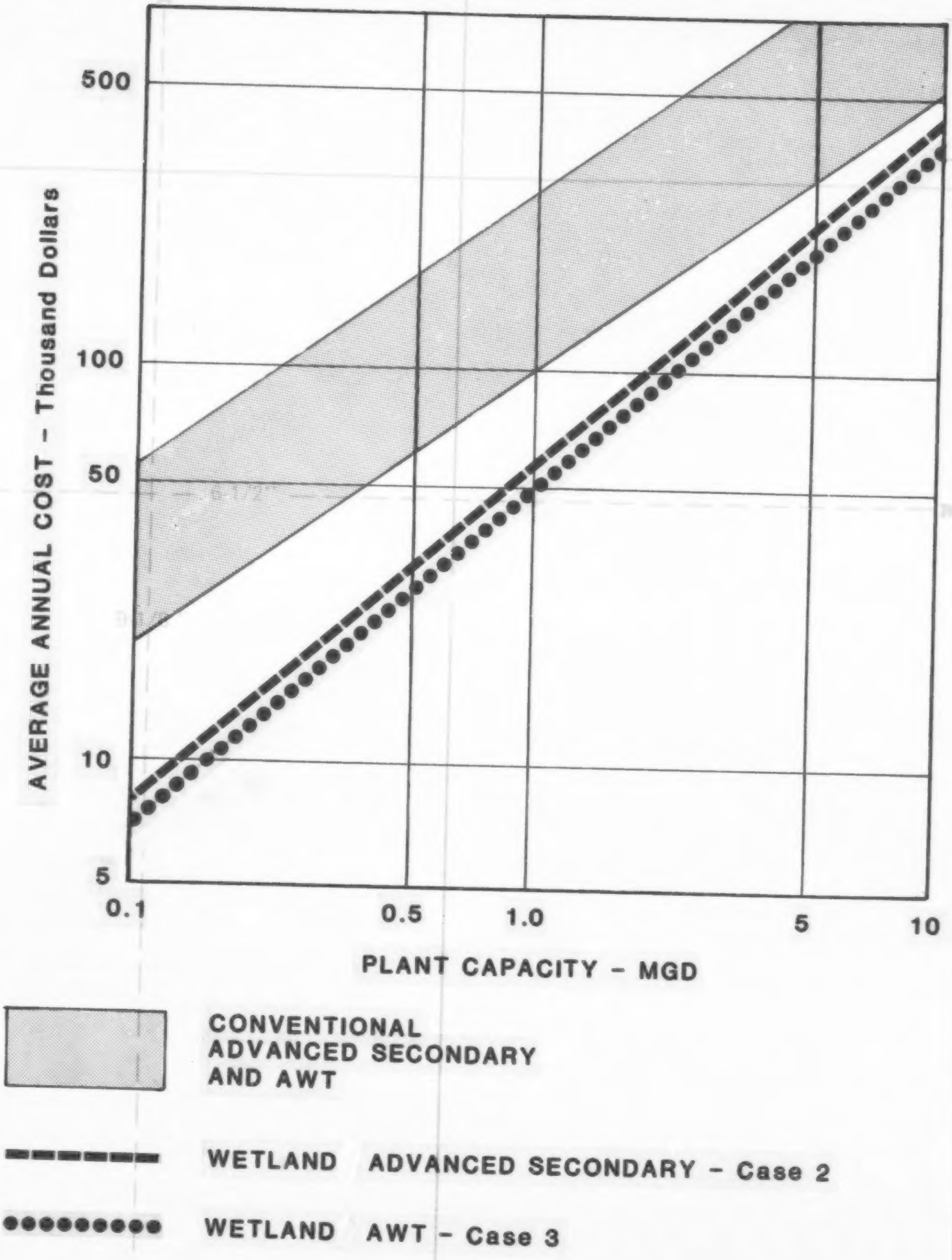

FIGURE 11. Average Annual Cost Comparison - Advanced System.

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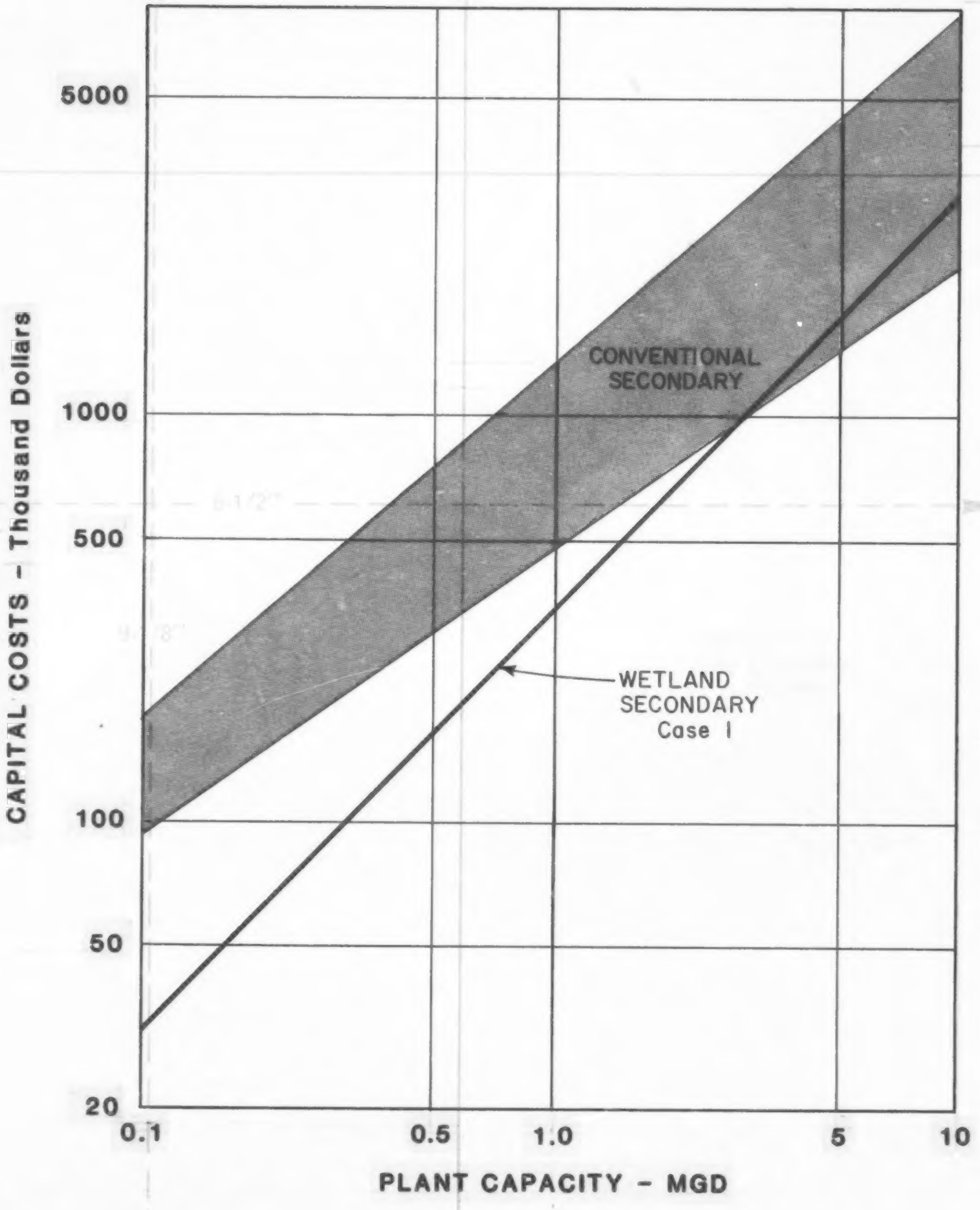

FIGURE 12. Capital Costs Comparison - Secondary System

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secondary treatment, and Figure 13 for advanced and AWT systems. These graphs show that the capital costs of wetlands are significantly lower than the conventional systems for all three cases. Graphs showing the annual O&M cost as a function of plant capacity are shown in Figures 14 and 15. Figure 14 presented the comparison for secondary treatment and Figure 15 advanced treatment figure 14 shows that the secondary wetland system's O&M costs increase with flow more rapidly than for conventional systems. For flows less than 3800 cu m/day (1.0 mgd) the annual O&M cost of wetland systems are less than or competitive to the conventional systems. As shown in Figure 15, the advanced wetland treatment system O&M costs are less than the conventional systems.

ENERGY ANALYSIS

The only energy expended in the example marsh wetland system is the gasoline used to operate the utility vehicle. Table 44 lists the energy consumed by the vehicle, based on an energy equivalent of 1.05×10^5 MJ per liter (1.27×10^5 Btu per gallon).

TABLE 44. ANNUAL ENERGY REQUIRED BY MARSH WETLAND SYSTEM

Flow (cu m/day)	MJ/year x 10^8	Btu/yr
400	0.63	2.01×10^7
800	1.27	4.04×10^7
2000	3.16	1.01×10^8
4000	6.32	2.01×10^8
8000	12.7	4.04×10^8

A range of energy requirements for conventional secondary and advanced treatment systems were developed from the information in the EPA I/A Manual (Reference 32) and Reference 24. The conventional secondary systems considered are activated sludge, trickling filter, rotating biological contactors, and contract stabilization. The conventional advanced and AWT systems used for comparison are activated carbon, dual media filters, nitrification, phostrip, ion exchange (for ammonia removal) and ferric chloride addition. Again, these energy requirements include solids removal (i.e. clarification) but not sludge handling (i.e. dewatering, digestion, disposal). Since the wetlands system consumes energy in the form of gasoline, the comparison between the wetlands and conventional plants will be made in Btu's. In converting the electrical kWh demand into equivalent Btu's, a conversion efficiency of 33 percent was used.

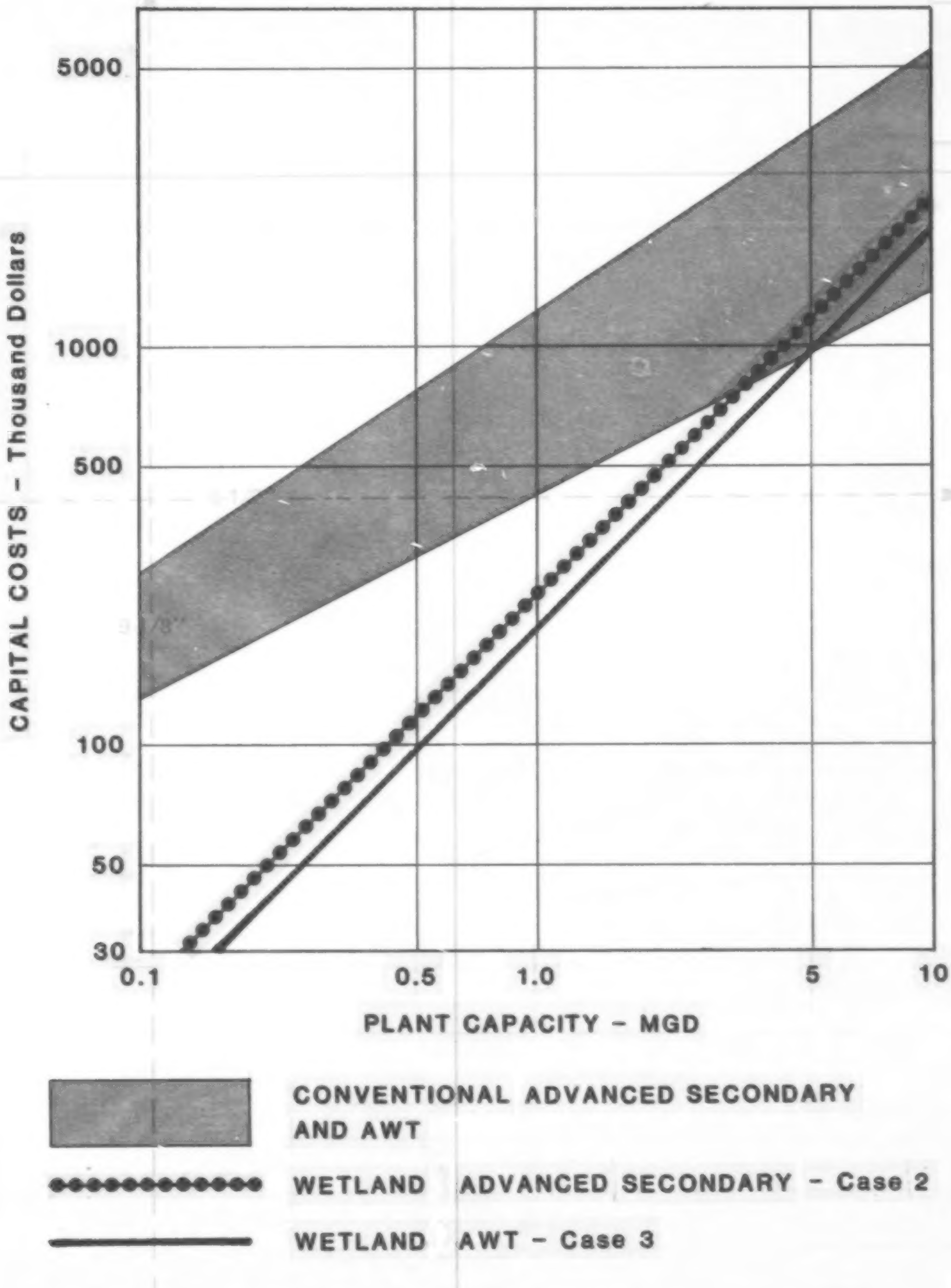

FIGURE 13. Capital Costs Comparison - Advanced System

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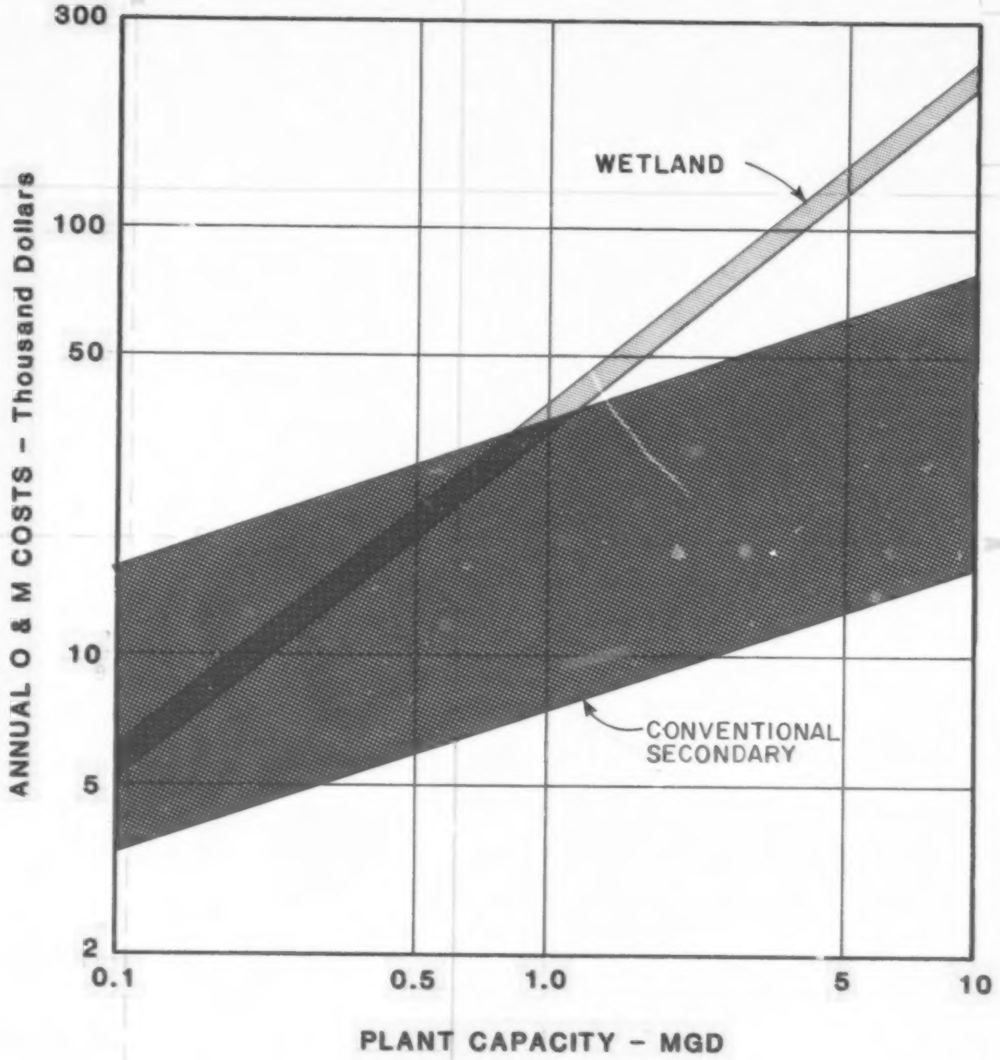

FIGURE 14. Annual O & M Costs Comparison - Secondary Treatment.

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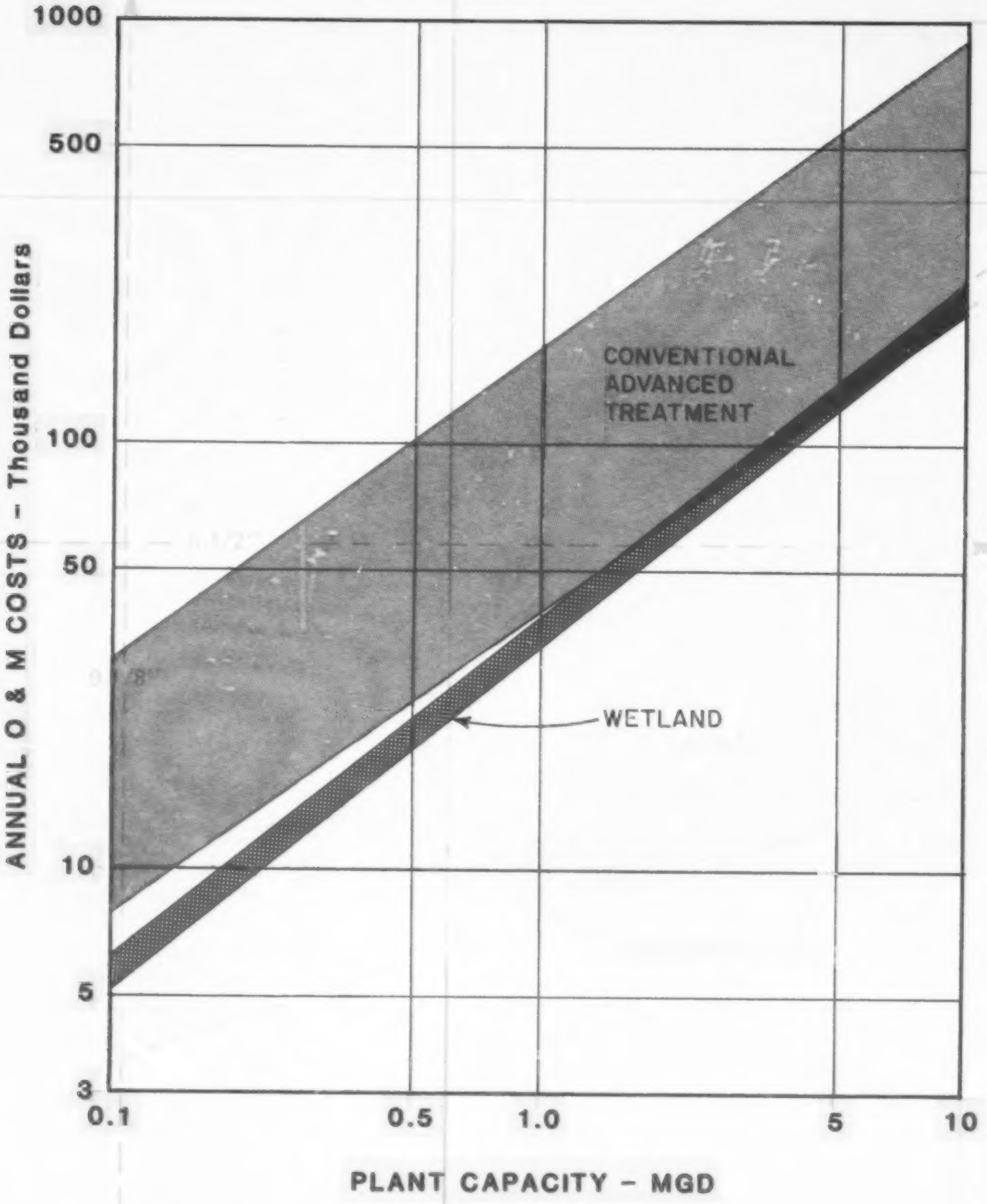

FIGURE 15. Annual O & M Costs Comparison - Advanced Treatment.

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Figure 16 presents a graphical comparison between the wetlands system and the conventional system. Estimated savings for secondary and advanced treatment systems are shown in Table 45. Since a range of energy demands for the conventional systems are presented in Figure 15, the mid-point energy value for the selected flow rates will be used for the comparison.

As the comparison shows, there is considerable energy savings (72 to 96 percent) with the use of wetlands systems for both secondary treatment and advanced treatment.

TABLE 45. COMPARISON BETWEEN WETLAND SYSTEMS AND CONVENTIONAL SYSTEMS ANNUAL ENERGY REQUIREMENTS (Btu/yr)

Treatment Type	Flow rates (cu m/day) 400	2000	4000	8000
Secondary				
Conventional	3.91×10^{8}	1.56×10^{9}	3.19×10^{9}	1.07×10^{10}
Wetlands	2.01×10^{7}	1.01×10^{8}	2.01×10^{8}	4.04×10^{8}
Savings	3.71×10^{8} 95%	1.46×10^{9} 94%	2.99×10^{9} 94%	1.03×10^{10} 96%
Advanced				
Conventional	7.75×10^{7}	3.85×10^{8}	8.13×10^{8}	1.52×10^{9}
Wetlands	2.01×10^{7}	1.01×10^{8}	2.01×10^{8}	4.04×10^{8}
Savings	5.74×10^{7} 74%	2.84×10^{8} 74%	6.12×10^{8} 75%	1.1×10^{9} 72%

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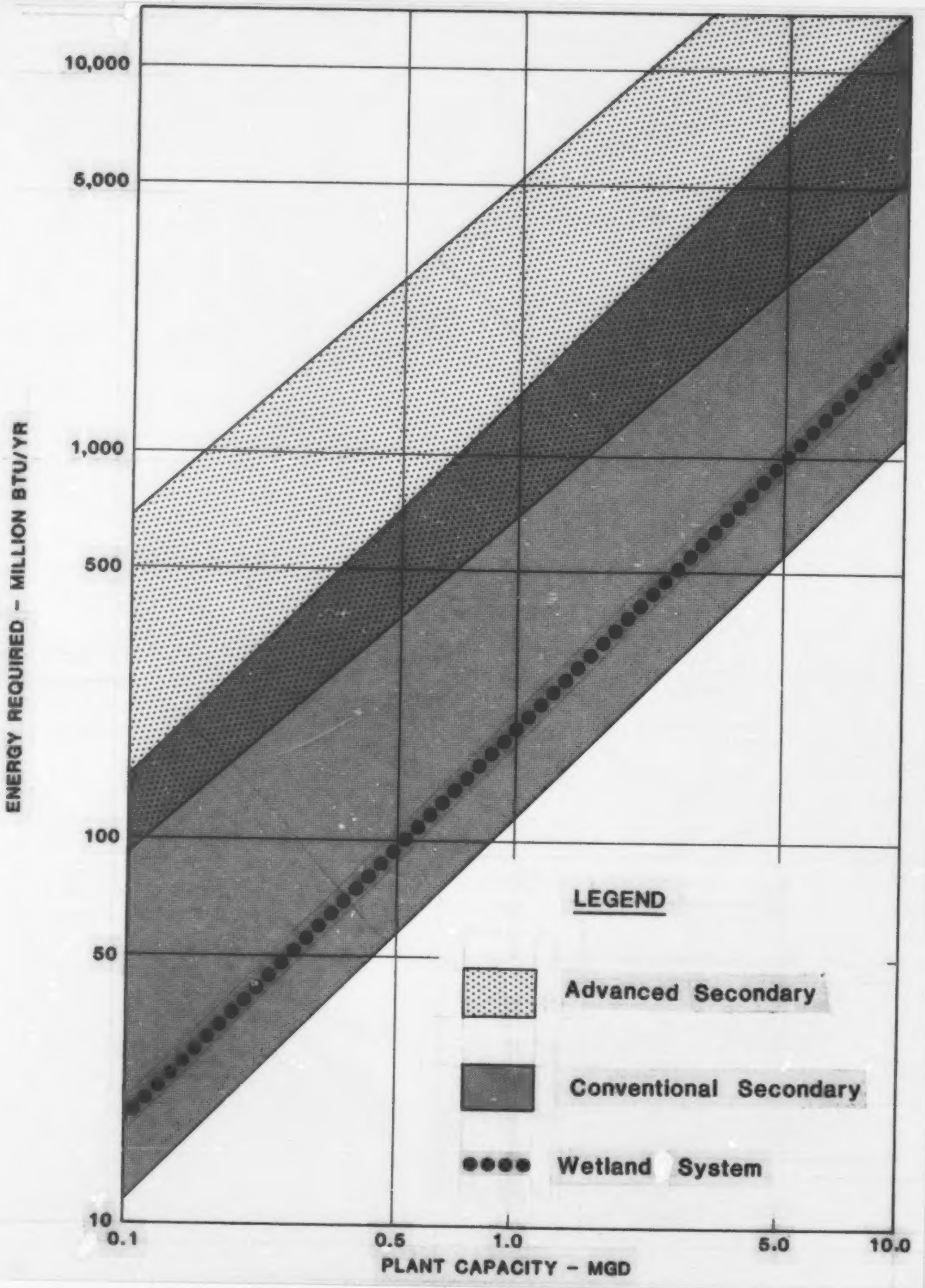

FIGURE 16. Comparison of energy demands.

SECTION 6

NATIONAL IMPACT ASSESSMENT

POTENTIAL MARKET

A constructed (artificial) wetland system appears to have greatest application for communities that have wastewater flows of less than 7,570 cu m/day (2 mgd). The flow limitations for natural wetlands are dictated by their existing characteristics.

Climate is not a limiting factor, since wetlands can exist in most parts of the Continental United States. The specific wetland type is designed for and the plant species are selected to adapt to the local climate. These vary across the nation. For example, in Florida there are extensive areas of swamps, cypress domes and strands , while in Wisconsin, Minnesota and Michigan there are numerous bogs and peatlands .

In most instances, a wetland will be treating waste from a rural community rather than from a large urban community. This is because wetlands are land intensive and are generally not economical in major urban areas with high land costs.

The major potential market for wetlands system includes communities with a flow of 7570 cu m/day (2 mgd)or less which requires secondary, advanced secondary or advanced waste treatment.

The EPA's 1978 Needs Survey (Reference 33) estimated the number of secondary treatment plants and treatment plants designed for more stringent treatment than secondary (advanced secondary and tertiary facilities) which will need to be constructed between 1978 and 2000 (see Table 46).

COST AND ENERGY IMPACTS

Cost

The possible savings to be realized by the utilization of wetland systems for secondary and advanced treatment is estimated by using the cost comparison graphs presented in Section 5. The approximate cost per plant was taken from the appro-

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TABLE 46. ESTIMATED TREATMENT PLANTS TO BE CONSTRUCTED BETWEEN 1978 AND 2000 (Reference 33)

Level of Treatment	Total Projected Flow (m^3/day) 1-400	401-1900	1910-4000	4001-7570
Secondary	2,790	1,089	169	52
Advanced	1,913	707	135	78

priate curve in Figures 10 and 11, at the higher end of the flow range (e.g., at 400 cu m/day for the 0 to 400 cu m/day range) and at the midpoint of the cost range. For secondary treatment, Case 1 was used, and for the advanced treatment, Case 2 was used. Table 47 shows the saving calculation.

If 10 percent of all of the secondary plants, with a flow less than 7570 cu m/day, that are anticipated to be constructed in the next 20 years were wetlands rather than conventional systems, the national cost savings in the year 2000 would be about $11.3 million. As Table 47 shows, in the year 2000, the total national savings related to the implementation of wetlands for all anticipated advanced treatment plants to be about $17.2 million.

Energy

An analysis similar to that for cost has been completed for the energy comparison. The approximate energy demand for both the wetlands system and conventional plants were taken from the energy comparison graph (Figure 15). Table 48 shows the calculated savings.

If 10 percent of the anticipated secondary plants (with flows below 7570 cu m/day) to be constructed in the next 20 years were wetlands, the average savings in energy consumption would be about $2.79x10^{11}$ Btu/year or 93 percent of the conventional plant usage. The savings expected from the implementation of wetlands systems in the year 2000 for advanced secondary and AWT at 10 percent of all anticipated plants (less than 7570 cu m/day) to be constructed in the next 20 years would be $4.59x10^{10}$ Btu/year, or 73 percent of the conventional plant demand.

TABLE 47. ESTIMATED ANNUAL AVERAGE COST OF 10 PERCENT OF THE ANTICIPATED TREATMENT PLANTS, 1978-2000 (ENR CCI 3384)

Treatment	Total Projected Flow (cu m/day)				
Type	0-400	401-1900	1910-4000	4001-7570	Total
Secondary					
Conventional					
Cost per plant	$28,000	$ 70,500	$111,000	$175,000	
10% TOTAL U.S.	7.81×10^6	7.68×10^6	1.88×10^6	9.1×10^5	1.83×10^7
Wetlands					
Cost per plant	10,500	18,000	78,300	153,000	
10% TOTAL U.S.	2.93×10^6	1.96×10^6	1.33×10^6	7.96×10^5	7.02×10^6
Savings					
(Conventional-	4.88×10^6	5.72×10^6	5.5×10^5	1.14×10^5	1.13×10^7
Wetlands)	62%	74%	29%	13%	62%
Advanced Secondary and AWT					
Conventional					
Cost per plant	$40,000	$122,000	$202,500	$325,000	
10% TOTAL U.S.	7.65×10^6	8.63×10^6	2.73×10^6	2.54×10^6	$\$2.16 \times 10^7$
Wetlands					
Cost per plant	8,700	14,300	60,100	116,000	
10% TOTAL U.S.	1.66×10^6	1.01×10^6	8.13×10^5	9.04×10^5	4.39×10^6
Savings					
(Conventional-	5.99×10^6	7.62×10^6	1.92×10^6	1.64×10^6	1.72×10^7
Wetlands)	78%	88%	70%	64%	79%

PERSPECTIVE

Cost

The 1978 Needs Survey (Reference 33) estimates that about $14 billion would be spent over the next 20 years in the United States for secondary treatment facilities including new construction, enlarging and upgrading existing plants. For plants with capacity less than 8,000 cu m/day the estimated cost is about $3.5 billion. The impact of the potential savings in the year 2000 from installing wetlands are minimal (less than 5 percent).

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TABLE 48. ESTIMATED ANNUAL ENERGY DEMANDS FOR THE ANTICIPATED TREATMENT PLANTS, IN BTU/YEAR, 1978-2000

Treatment Level	Total Projected Flow (cu m/day)				
	0-400	401-1900	1910-4000	4001-7570	Total
Secondary					
Conventional per plant	3.91×10^8	1.56×10^9	3.19×10^9	1.07×10^{10}	
10% Total U.S.	8.54×10^{10}	1.31×10^{11}	4.15×10^{10}	4.28×10^{10}	3.01×10^{11}
Wetland per plant	2.01×10^7	1.01×10^8	2.01×10^8	4.04×10^8	
10% Total U.S.	5.61×10^9	1.10×10^{10}	3.40×10^9	2.10×10^9	2.21×10^{10}
Savings (Conventional-Wetlands)	7.98×10^{10}	1.20×10^{11}	3.81×10^{10}	4.07×10^{10}	2.79×10^{11} 93%
Advanced Secondary and AWT					
Conventional per plant	7.75×10^7	3.85×10^8	8.13×10^8	1.52×10^9	
10% Total U.S.	1.25×10^{10}	2.31×10^{10}	8.94×10^9	1.82×10^{10}	6.27×10^{10}
Wetland per plant	2.01×10^7	1.01×10^8	2.01×10^8	4.04×10^8	
10% Total U.S.	3.85×10^9	7.14×10^9	2.71×10^9	3.15×10^9	1.69×10^{10}
Savings (Conventional-Wetlands)	8.65×10^9	1.60×10^{10}	6.12×10^9	1.51×10^{10}	4.59×10^{10} 73%

For advanced secondary treatment and AWT facilities (including construction, enlarging and upgrading) the needs survey estimates that $20 billion will be spent over the next 20 years. For plants with flows less than 8,000 cu m/day, the estimate is about $4.9 billion. The impact of possible savings in the year 2000 on the national budget for advanced treatment are minimal.

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For both secondary and advanced treatment the estimated national budget over the next 20 years is about $34 billion. For those facilities with flows under 8,000 cu m/day the estimate is about $8.4 billion. The impact of possible savings in the year 2000 on the national budget for secondary and advanced treatment are minimal.

Energy

As reported in the EPA publication Energy Conservation in Municipal Wastewater Treatment, (Reference 34) the 1990 estimated energy consumption at publicly owned treatment works for secondary treatment is 216.51x10^{12} Btu/year and 40.40x10^{12} Btu/year for tertiary treatment. The 1990 national energy use is estimated to be 114x10^{15} Btu/year.

The savings realized by using wetlands for secondary treatment (2.79x10^{11} Btu/year) is about 0.13 percent of the national energy required for secondary treatment in 1990. The savings from advanced treatment wetlands (4.59x10^{10} Btu/year) is 0.11 percent of the national tertiary treatment 1990 energy budget. The savings realized by the use of secondary and advanced treatment wetland systems (3.25x10^{11} Btu/year as presented in Table 48) are insignificant (less than 0.01 percent) to the total 1990 National Energy Use Budget. However, the impact on a small local community may be significant.

MARKETABILITY/RISK

As previously discussed, the market for wetland systems is limited in relation to the market for all wastewater treatment facilities in the United States. This market is generally limited to suburban and rural communities that have existing natural wetlands or large areas of reasonably priced land, and wastewater flows generally less than 7,570 cu m/day (2 mgd). However, the largest number of facilities needed are in this range.

The marketability of wetland is dependent upon wetland availability and the risk related to wetlands being a relatively unproven wastewater treatment technology, and because it is a natural system. The risk is reduced with each wetlands system that is implemented. As more performance data are developed, the more refined and reliable the design criteria becomes. Natural systems have the benefit of low O&M costs, but there is also the drawbacks of the limited control over the process. This risk may be reduced as design parameters become more established and through additional experiences with wetland systems.

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A community may justify the risk by taking into account the favorable aspects of a wetlands system and the known risks involved with conventional plants. The annual costs and energy requirements of a wetlands system are considerably lower than for conventional plants, which is probably the greatest incentive for a small community.

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SECTION 7

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CONTACTS

GENERAL

William R. Duffer, Ph.D.
US EPA
Robert S. Kerr Environmental
 Research Laboratory Center
P.O. Box 1198
Ada, OK 74820
(405) 332-8800

Robert K. Bastian
US EPA
401 "M" Street, S.W.
 (WH-547)
Washington, D.C. 20460
(202) 382-7378

PILOT AND FULL SCALE FACILITIES

City of Arcata, CA:
R.A. Gearheart, Ph.D.
Pilot Project Manager
736 "F" Street
Arcata, CA 95521
(707) 822-5951

Brillion, WI
Dr. Frederic Spangler
Associate Professor of Biology
University of Wisconsin/Oshkosh
Oshkosh, WI 54901

Concord, MA:
Jerry Smith
IEP
534 Boston Post Road
P.O. Box 438
Wayland, MA 01778
(617) 358-5156

Drummond, WI:
Mr. William Kappel
U.S.G.S.
521 W. Seneca Street
Ithaca, NY 14850
(607) 272-8722

Dundas, Ontario:
Mrs. Alena Mudroch
Environmental Contamients
 Division
National Water Research
 Institute
P.O. Box 5050
867 Lake Shore Road
Burlington, Ontario L7R 4A6
CANADA
(416) 637-4389 secretary x4678

Hamilton Marsh, NJ:
Dr. Robert Simpson
Biology Department
Rider College
Lawrenceville, NJ 08648
(609) 896-5092

Houghton Lake and Bellaire, MI:
Dr. Robert Kadlec
Dept of Chemical Engineering
University of Michigan
Ann Arbor, MI 48109
(313) 764-3362

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Francesca Demgen
Demgen Aquatic Biology
118 Mississippi Street
Vallejo, CA 94590
(707) 643-5889

Neshaminy Falls, PA:
Dr. Grover Emrick
President
A.W. Martin Asso, Inc
P.O. Box 190
King of Prussia, PA 19406
(215) 265-2700

Reedy Creek-Wetlands, FL:
Mr. Robert Kohl
Reedy Creek Utilities Co., Inc
P.O. Box 40
Lake Buena Vista, FL 32830
(305) 824-4026
switchboard (305) 824-2222

Vermontville, MI:
Mr. Jeff Sutherland
c/o Williams & Works, Inc.
611 Cascade West Parkway
Grand Rapids, MI 49506
(616) 942-9600

Whitney Park, FL:
Dr. Kathy Ewel
School of Forestry Resources
& Conservation
University of Florida
Gainesville, FL 32611
(904) 392-1850

Wildwood, FL:
Dr. John Zoltek
Department of Environmental
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University of Florida
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